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RESEARCH MEMORANDUM

A FLIGHT EVALUATION OF THE STABILITY AND CONTROL OF THE X-4 SWEPT-WING SEMITAILLESS AIRPLANE

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High-Speed Flight Station
Edwards, Calif.

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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A FLIGHT EVALUATION OF THE STABILITY AND CONTROL OF THE X-4 SWEPT-WING SEMITAILLESS AIRPLANE

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SUMMARY

An evaluation of the handling qualities of the Northrop X-4 swept-wing semitailless airplane is reported covering a speed range from stall to a Mach number of 0.92 primarily at 30,000 feet. The data are presented as peculiar to the X-4 with little attempt to generalize over the tailless field.

The characteristic problems of tailless airplanes at low speeds, such as marginal longitudinal stability and control resulting in close center-of-gravity limits, were encountered. Throughout the speed range typical swept-wing instability and buffet characteristics were recorded at lower normal-force coefficients than with tail-on airplanes of similar sweep. At high speeds the X-4 exhibited yawing and rolling oscillations from a Mach number of 0.76 to Mach numbers above 0.90 where the motions diverged to unsafe values. At a Mach number of 0.88 the yawing and rolling coupled with a pitching motion causing oscillations about all three axes. Total elevon effectiveness decreased rapidly with increasing Mach number above 0.75 at high lifts and above a Mach number of 0.87 at low lifts, severely restricting maximum lift attainable and maneuverability. At Mach numbers above 0.90 the elevon angles required to trim in level flight became prohibitive and maneuverability all but disappeared.

INTRODUCTION

The Northrop semitailless X-4 airplane was built as part of the joint NACA-Air Force-Navy research airplane program. The purpose of building the X-4 was to determine if the absence of a horizontal tail in the wake of unsteady wing flow would yield improvement in buffet and stability characteristics over tailed airplanes in the transonic region. Preliminary results of this flight program from Northrop demonstration tests and the Air Force evaluation tests are given in references 1 and 2, respectively.

The investigation presented herein was (1) to determine whether the unsatisfactory flying qualities that characterized past tailless airplanes were alleviated to an acceptable degree in the X-4, and (2) to accomplish the original objective, as stated above, by extending the analysis into the supercritical speeds. Emphasis in this program was placed upon those stability and control characteristics attributable to the absence of a horizontal tail and upon those characteristics which imposed limits upon the airplane capabilities.

These data are from tests flown and analyzed at the NACA High-Speed Flight Station at Edwards, Calif., and are presented as peculiar to the X-4 with little attempt to generalize over the tailless field.

SYMBOLS

A_Z	normal acceleration factor (the ratio of the net aerodynamic force along the airplane Z-axis to the weight of the airplane)
b	span, ft
b	total damping coefficient of longitudinal oscillations $\left(1.386/T_{1/2}\right)$, per sec
$C_{1/10}$	cycles for longitudinal oscillation to damp to one-tenth amplitude
C_l	rolling-moment coefficient
C_{l_β}	effective dihedral parameter, per radian
C_m	pitching-moment coefficient
C_{m_α}	rate of change of pitching-moment coefficient with angle of attack, $dC_m/d\alpha$, per deg
C_{m_β}	static pitching-moment coefficient due to sideslip, per deg
C_{N_A}	normal-force coefficient, WA_Z/qS
C_{N_α}	normal-force-curve slope, $dC_N/d\alpha$, per degree or radian as noted
$\bar{c}$	wing mean aerodynamic chord, M.A.C., ft

F_e	stick force, lb
F_r	rudder pedal force, lb
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
I_X	moment of inertia about X-axis, $slug-ft^2$
I_Y	moment of inertia about Y-axis, $slug-ft^2$
M	Mach number
P	period, sec
p	rolling velocity, radians/sec unless otherwise noted
pb/2V	wing-tip helix angle, radians
q	pitching velocity, radians/sec
q	dynamic pressure, lb/sq ft
r	yawing velocity, radians/sec
S	wing area, sq ft
S.P.	stick position, in.
$T_1/2$	time for oscillation to damp to one-half amplitude, sec
t	time, sec
V	true velocity, ft/sec
V_i	indicated airspeed, mph
W	airplane weight, lb
α	airplane angle of attack, deg
β	sideslip angle, deg
δ_a	effective lateral control angle, $\delta_{e_L} - \delta_{e_R}$, deg

δ_e effective longitudinal control angle, $\frac{\delta_{eL} + \delta_{eR}}{2}$, deg

δ_r rudder angle, deg

Subscripts:

L left

R right

t total

DESCRIPTION OF AIRPLANE

A three-view drawing of the Northrop X-4 tailless airplane used in these tests is shown in figure 1 and photographs are shown as figure 2. The physical characteristics of the airplane are listed in table I.

The X-4 elevon system is a closed irreversible hydraulic powered system. Power is applied to the surface by means of servo-valve controlled cylinders. The servo valves, which are an integral part of the cylinder assembly, are operated by the pilot's stick through a cable system. The control stick "feel" is provided synthetically by springs for both lateral and longitudinal displacements plus a dynamic pressure sensing bellows for longitudinal displacements. The longitudinal breakout force envelopes are shown in figure 3 for two values of dynamic pressure. These data represent the envelope of the force required to initiate motion from all positions.

The X-4 rudder is directly linked to the rudder pedals by a cable and bell crank system. Originally the rudder was electrically operated by a four-speed actuator. The maximum speed of 25° per second was found to be too slow in early tests.

Dive brakes are provided by splitting the trailing edge inboard of the elevons to any desired angle up to 60°. Originally, provision was made for use of the lower surface of the dive flaps for landing flaps but insufficient longitudinal control was available to trim out the down pitching moment incurred, so this provision was removed.

INSTRUMENTATION

Standard NACA optically recording instruments were used to record the airspeed, altitude, control positions and forces, accelerations at the center of gravity, angular velocities, sideslip angle, and angle of attack. The angle of attack was referred to the fuselage center line and was not corrected for position error or boom deflection. The true airspeed and altitude were determined from the fin boom airspeed system up to a Mach number of 0.93 by using the NACA radar phototheodolite method (ref. 3). Later test airspeeds were determined from the nose boom system. In neither case were the recorded airspeeds corrected for lift effects.

ACCURACY OF MEASUREMENT

The estimated accuracy of the quantities measured in the test is as follows:

Quantity	Accuracy
Normal acceleration factor	±0.03
Lateral acceleration factor	±0.02
Pressure altitude, ft	±800
Mach number:	
Below pitch-up	±0.02
Above pitch-up	±0.04
Period of oscillation:	
Longitudinal, sec	±0.2
Lateral and directional, sec	±0.1
Rolling velocity, radians/sec	±0.02
Pitching velocity, radians/sec	±0.01
Time for oscillation to damp to one-half amplitude:	
Longitudinal, sec	±0.2
Lateral and directional, sec	±0.5
Airplane angle of attack, deg	±0.5
Sideslip angle, deg	±0.25
Longitudinal control angle, deg	±0.5
Lateral control angle, deg	±0.5
Rudder angle, deg	±0.5
Center-of-gravity position, percent $\bar{c}$	±0.25

RESULTS AND DISCUSSION

Static Longitudinal Stability Characteristics

Low-speed stability characteristics.- The initial tests on the Northrop X-4 airplane showed that low moment effectiveness of the elevon longitudinal control imposed close limits upon the low-speed operation of the airplane. Longitudinal data recorded during take-offs and low-speed flight early in the program are presented in figure 4. At a center-of-gravity location of 22 percent mean aerodynamic chord in take-off configuration the stability deteriorated rapidly at an indicated velocity of 200 mph which caused concern to the pilot. With the gear up and the center of gravity at 21.4 percent mean aerodynamic chord the scatter in the data at V_i = 250 mph indicates a sensitive and nearly neutrally stable airplane which was confirmed by the pilot. With the center of gravity at 16.5 percent mean aerodynamic chord, elevon low moment effectiveness necessitated full control at V_i = 150 mph and normal-force coefficient of 0.58 in landing configuration.

On the basis of these results and the pilots' opinions the characteristics were assessed as follows:

1. With a center-of-gravity location of 22 percent mean aerodynamic chord the static stability was dangerously low at an indicated velocity of 200 mph.

2. Any center-of-gravity location aft of 19 percent mean aerodynamic chord was unsatisfactory with the airplane's control system which has the usual high breakout characteristics associated with current irreversible systems.

3. The forward center-of-gravity limit was considered to be 16.5 percent mean aerodynamic chord because of insufficient longitudinal control power for approach and landing.

In view of the above considerations, extreme center-of-gravity limits were held between 16.5 and 18.5 percent mean aerodynamic chord for the subject tests, a very restricted range compared to contemporary tailed airplanes. Most of the maneuvers reported were made with a center-of-gravity location between 17 and 18 percent mean aerodynamic chord.

Low-speed stall characteristics.- Straight flight approaches to stall (fig. 5) were characterized by a mild roll-off and buffeting at normal-force coefficients about 0.2 below maximum attainable with control available in the landing configuration. The left rudder and aileron applied by the pilot near time 24 seconds, resulting in the right sideslip shown, was required to prevent a right roll-off tendency. The

increase in normal-force coefficient and angle of attack after the elevons were at maximum deflection indicates a mild stall instability but the airplane apparently becomes stable again at higher angles as indicated at time 36 seconds where lift and angle of attack begin to decrease at constant elevon angles. Mild spinning tendencies were reported by the pilots but were not considered dangerous. Control deflections larger than those indicated in figure 5 could induce spin.

High-speed longitudinal trim characteristics.- At the higher speeds the elevator angles required for constant C_{N_A}, as shown in figure 6, indicate trends similar to those of most airplanes at supercritical Mach numbers. These data were recorded during constant Mach number - constant rate wind-up turns of about 12-second total duration. In the region shown as stable the airplane is stable with lift at constant speed as evidenced by the contour gradient of figure 6. The trim variation through a Mach number of 0.77 has no ready explanation. The decreasing angles required between Mach numbers of 0.88 and 0.90 may be associated with the high lift-curve slopes shown in figure 7 at those speeds. These data represent the recorded slope of lift with angle of attack near level-flight normal-force coefficients at 30,000 feet during airplane maneuvers of low enough rate to consider nearly trim conditions. At a Mach number of about 0.88 the X-4 exhibited a radical departure from expected lift-curve slope at low lifts. Predicted lift-curve slope with $\delta_e = 0^\circ$ from reference 4 is shown for comparison. Insufficient data are available above a Mach number of 0.90 to determine the trend.

Elevon maneuvering effectiveness.- The elevon maneuvering effectiveness $d\delta_e/dC_{N_A}$ as indicated by the contour gradient of figure 6 is plotted in figure 8 for a C_{N_A} of 0.15, which is near level-flight lift coefficients, and for accelerated flight C_{N_A} of about 0.45 through the speed range. At lower lifts the control effectiveness reduces rapidly above a Mach number of 0.87. This loss was predicted in reference 4. At higher lifts, however, control effectiveness decreases rapidly above $M = 0.75$ in the stable region of flight shown in figure 6. This rapidly deteriorating control power with increased speed and acceleration severely limited the test envelope because insufficient control was available to maneuver or recover from dives necessary to attain high speeds. The major loss in control power at low lifts is attributable to loss in flap effectiveness. The static stability as determined from the airplane's natural frequency at level-flight lifts indicates less than a twofold increase in C_{m_α} at high speeds as shown in figure 9. Comparison of figure 9 with figure 8 shows a much greater change in apparent stability at near level-flight lift coefficients. Thus a large proportion of the apparent increase in stability arises from reduced flap effectiveness.

The reduced control power indicated by figure 8 at higher lift coefficients implies increased stability with lift in the region marked stable (fig. 6). However, the subsequent discussion will show that stability with angle of attack begins to decrease in this region because of the nonlinearity of the lift-curve slope at higher lifts.

Accelerated flight stability.- A stability problem experienced with the X-4 airplane and typical of all swept-wing airplanes was that of an abrupt decrease in longitudinal stability apparently associated with premature tip separation and the resulting inboard shift in span loading at moderate to high normal-force coefficients (ref. 5).

Representative time histories of angle of attack, normal-force coefficient, and longitudinal control angle during wind-up turns at constant Mach numbers for the X-4 airplane (fig. 10) show that at the lower Mach numbers where the rate of increase of elevon deflection remains fairly constant, the angle of attack begins to increase rapidly at the higher values of normal-force coefficient indicating an abrupt decrease in stick-fixed stability. For a Mach number of 0.87, however, a large increase in apparent stability as evidenced by maximum elevon deflection required for small angle-of-attack change is indicated. It is noteworthy that at Mach numbers lower than 0.70 there is generally no associated abrupt rise in normal-force coefficient. The variation of longitudinal control angle with angle of attack (fig. 11) shows the abrupt decrease in stability more clearly. For example, at a Mach number of 0.63 the variation of control angle with normal-force coefficient indicates increasing stability, whereas in reality the angle of attack is increasing greatly with relatively little control motion and a very unstable condition exists. The variation of δ_e with α above the slope change is open to question from static considerations as the severity of the pitch-up is obscured by control motion and dynamic effects. In order to correct the data for dynamic influence, control-effectiveness data for C_{N_A} in the unstable regions would be required, and these data are unavailable.

In figure 12, comparative boundaries (defined as the normal-force coefficient at which a marked change in $d\delta_e/d\alpha$ occurs in the direction of reduced stability) are shown for three airplanes: the X-4, the F-86A (ref. 5), and the D-558-II (ref. 6). It is noteworthy that once this boundary is penetrated, a generally uncontrollable increase in angle of attack and normal-force coefficient occurs which is more pronounced at the higher Mach numbers. The severity of the instability varies between airplanes and depends in part upon the rate of entry and rate of application of corrective control. The instability on the tailless airplane that occurs below a Mach number of 0.70 with no associated abrupt increase in normal-force coefficient is not considered dangerous except in the take-off and landing case. The X-4, however, did not pitch-up on take-off

or landing because of insufficient longitudinal control to reach high lift. The instability that occurs with an abrupt increase in normal force at Mach numbers between 0.70 and 0.83 on the X-4 airplane, and higher on conventional airplanes, is dangerous and imposes a serious limitation on the use of these airplanes. At Mach numbers above 0.83 insufficient longitudinal control was available to maneuver the tailless airplane to the decreased stability boundary.

Buffet and maximum lift.- The high-lift static instabilities at Mach numbers below 0.83 appeared to the pilot to occur simultaneously with the onset of buffet. Since an original purpose in building the X-4 airplane was to determine buffet characteristics without the influence of a horizontal tail, a comparison of the X-4 and the D-558-II (ref. 7) airplanes is shown in figure 13. The normal-force coefficient at which buffet intensity rises is shown for both airplanes. The entire flight envelope of the X-4 is essentially limited to normal-force coefficients below the buffet intensity-rise boundary of the D-558-II. Incipient buffet occurs at C_{N_A} about 0.15 below that of the D-558-II. The objectionable, or perhaps, intolerable buffet boundaries shown are based largely upon pilot opinion. The results of detailed investigation of X-4 buffet is presented in reference 8.

The maximum normal-force coefficients obtained in the subject tests are shown by the upper X-4 boundary of figure 13. This curve represents the envelope of the maximum normal force attained. At Mach numbers above 0.83 maximum normal force is limited by the low total effectiveness of the elevons; in addition, a decrement is imposed by the large elevon angles required to maneuver at Mach numbers above about 0.80. Below $M = 0.83$ and above $M = 0.60$ the indicated values were reached during the uncontrollable instability previously discussed and are influenced by pitching rate, arbitrary control position, and rate of control application to overpower the instability. Below a Mach number of 0.60 the pitch-up had little associated increase in lift and hence maximum attainable lift is indicated, except for the 1g stall where again control limitations predominate.

Dynamic Stability Characteristics

The dynamic longitudinal and lateral and directional characteristics had three outstanding features:

1. A small amplitude ($\pm 1/2^{\circ}$) undamped lateral-directional oscillation between Mach numbers of 0.76 and 0.90.

2. An undamped steady oscillation about three axes at a Mach number of 0.88 which appeared to be predominantly pitching ($\pm 0.25g$) to the pilot.

3. A divergence of the lateral and directional motion for Mach numbers at or above 0.90.

The second case was primarily responsible for limiting the acceptance tests (ref. 1) and the Air Force evaluation program (ref. 2) to a Mach number of 0.88. The third case, together with the previously discussed control problem, limited the subject tests to a Mach number of 0.92.

Figure 14 shows the airplane motions typical of the speed range mentioned above. The upper part of figure 14(a) represents the response to an abrupt longitudinal input at a Mach number of 0.87. The pitching damps to nearly zero in about 4 seconds and there is little, if any, yawing and rolling that results from the pitching. The lower part of figure 14(a) shows the motions resulting from a rudder input. Large motions damp to low amplitudes. The small residual motion persists at all speeds above a Mach number of 0.76 and is of very small magnitude. Figures 14(b) and (c) are simultaneously recorded data of self-exciting motions.

Period and damping.- The longitudinal characteristics over the flight range, analyzed without considering lateral motions, are presented in figures 15 and 16. The longitudinal damping is compared with the F-86A for an altitude of 30,000 feet. The lateral and directional characteristics are presented in figures 17 and 18. The times to damp and damping factors shown are obtained from the envelopes of disturbed motions before subsiding into the residual steady-state motions. In figure 18 the variation of time to damp with period is shown at several altitudes and compared to military requirements (ref. 9). As is illustrated, the specifications are not met.

Undesirable oscillations at high speeds.- During the investigation of the semitailless X-4 airplane, it became apparent that peculiarities attributable to the absence of a horizontal tail could not be considered only longitudinal at Mach numbers above 0.87. One of the highly undesirable dynamic characteristics of the X-4 is the occurrence of a small amplitude oscillation about all three axes at a Mach number of 0.88. A time history of such a motion is shown in figure 14(b). It had been thought that the objectionable mode was due to zero total damping for small displacements. Recent computations, however, have indicated that a geometric coupling of the residual yawing and rolling mentioned above with the pitching motion could account for most of the longitudinal mode at a Mach number of 0.88.

The original hypothesis was supported by the following factors:

1. At Mach numbers between 0.76 and 0.90 a yawing oscillation of approximately $\pm 0.50^{\circ}$ persists.

2. All yawing and rolling motions induce pitching at twice the frequency. Static pitching moment due to sideslip C_{m_β} is negligible, but the angle-of-attack variation due to yawing and rolling is appreciable.

3. Analysis considering inertia coupling shows that the contribution of $rp(I_X - I_Y)$ is negligible.

4. In the Mach number range from 0.87 to 0.89 the natural frequency in pitch is twice that of yaw.

5. The ratio of amplitudes α/β determined from time histories of damped and steady-state motions varies with Mach number with the characteristic appearance of a response curve peaked at a Mach number of 0.88.

Since inertia coupling did not account for the motion, an analysis of geometric coupling effects was made equating the first-order displacement and rotary longitudinal motions to forcing functions. The required derivatives were determined from flight and wind-tunnel data. The damping values were obtained from the envelopes of the motion before subsiding into the residual mode. The forcing function was the geometric angle-of-attack input due to yawing and rolling. The results of the analysis showed that for a given case the input angle of attack (forcing function) due to geometric coupling could account for a major portion of the motion measured in flight. However, quantitative data are difficult to obtain because to meet the requirements of the classicized analysis the wing fuel distribution, the static margin, and the Mach number must be known within very small relative limits.

The total damping may become zero for small-amplitude motions at Mach numbers above 0.90 under accelerated conditions. This is shown in the time history of a speed run (fig. 19) to the maximum test Mach number of 0.92, during which the pilot commented that the characteristic "porpoising" had diminished and that a relatively smooth flight region had been reached at Mach numbers above 0.90. Examination of figure 19 shows that as a Mach number of 0.90 was exceeded, the porpoising did tend to diminish coincident with a reduction in normal acceleration factor below 1. As the acceleration factor was increased to 1 at a Mach number of 0.92, however, the oscillation reappeared with a frequency slightly higher than that experienced at a Mach number of 0.88. As the acceleration factor was increased above 2, the frequency almost doubled with no corresponding change in the rolling and yawing oscillation, indicating that coupling effects were not a major contributing factor to this higher-frequency porpoising. The increase in frequency with acceleration factor corresponds to almost a fourfold increase in static stability C_{m_α} between normal-force coefficients of 0.1 and 0.3 at a Mach number of 0.90, accounting for some of the loss of elevon

control power, $d\delta_e/dC_{N_A}$, at the higher normal-force coefficients shown in figure 8.

The residual small-amplitude lateral and directional oscillation continues to a Mach number of 0.90 where upon two occasions it diverged as shown in figure 14(c). The first occurrence was during a prolonged speed run above M = 0.90. The initial divergence was very slow. In a subsequent case, which is illustrated in figure 14(c), the divergence occurred after deliberately disturbing the airplane. The divergence did not appear on other occasions at and above a Mach number of 0.90 apparently because the time at speed was short and the airplane was not disturbed to induce the motion. The time history of the divergence in figure 14(c) shows that maximum double amplitudes of sideslip angle of 15° and rolling velocity of about 3 radians per second were reached in about 8 seconds following the initial disturbance. Regardless of the previously mentioned control limitations, this divergence was considered dangerous and limited test speeds to a Mach number of 0.92.

Static Lateral and Directional Stability and Control

Sideslip characteristics.- The static lateral and directional characteristics are considered independent of longitudinal tail volume and hence are not necessarily presented as tailless airplane characteristics except that the X-4 configuration imposed a short vertical-tail length.

The steady sideslip characteristics of the X-4 airplane were generally satisfactory over the test Mach number range as shown by the results presented in figure 20. The apparent directional stability parameter $d\delta_r/d\beta$ (fig. 21(a)) was positive and high except for low values observed for small angles of sideslip at Mach numbers above about 0.70 (figs. 20(c) and 20(d)). This may be in part responsible for the aforementioned yawing oscillation. The apparent dihedral effect $d\delta_{a_t}/d\beta$ was positive and increased with normal-force coefficient, as is expected for swept-wing airplanes. The change in longitudinal trim with sideslip angle was desirably small. The data for a Mach number of 0.90 (fig. 20(e)) are subject to some question since they were obtained while the airplane was oscillating about all three axes just prior to a divergence of the lateral and directional oscillation.

Dihedral and lateral control characteristics.- The variation with Mach number of the effective dihedral parameter C_{l_β} is shown in figure 21(b). The effective dihedral was determined by the method suggested in reference 10 as follows:

$$C_{l_\beta} = \left[\frac{d(pb/2V)}{d\delta_{a_t}}\right]\left[\frac{dC_l}{d(pb/2V)}\right]\left(\frac{d\delta_{a_t}}{d\beta}\right)$$

The damping-in-roll term $\frac{dC_l}{d(pb/2V)}$ was obtained from low-speed model data given in reference 11 and approximate compressibility corrections to a Mach number of 0.90 were applied in accordance with the method of reference 12. The term $\frac{d\delta_{a_t}}{d\beta}$ was obtained from steady sideslip data. The $\frac{d(pb/2V)}{d\delta_{a_t}}$ term was obtained from rudder-fixed aileron roll data at 30,000 feet.

The lateral-control characteristics of the X-4 are presented in figures 22 to 24. The linear variation of wing-tip helix angle $pb/2V$ with aileron angle (fig. 22) up to 33° total flap deflection is noteworthy. Including the longitudinal trim angles required, this angle corresponds to individual flap angles of the order of 35°. As shown in figures 23 and 24, the wing-tip helix angle per unit aileron angle and the rolling velocity variations with Mach number show the beginning of the same trend in severe loss of flap effectiveness at Mach numbers above 0.85 as the longitudinal control previously discussed. The results in figures 23 and 24 show that the lateral control appears adequate at Mach numbers above about 0.60, although at lower Mach numbers the Air Force requirements of either $pb/2V$ of 0.09 or a rolling velocity of 220° per second were not met.

In view of the pilots' observations that the lateral control was highly satisfactory even below Mach numbers of 0.60 where requirements were not met satisfactorily, it appears that a more realistic criterion than that currently specified is needed to describe satisfactory lateral control. A tentative criterion in reference 13, based on experience gained in flying several research airplanes, suggests a time of 1 second to reach an angle of bank of 90°.

CONCLUSIONS

The handling-qualities evaluation of the swept-wing semitailless Northrop X-4 airplane has led to the following conclusions:

1. At low speeds marginal stability restricted the aft center-of-gravity travel to 19 percent mean aerodynamic chord and low longitudinal

control power restricted the forward limit to 16.5 percent mean aerodynamic chord yielding less than 3 percent permissible center-of-gravity travel. The low longitudinal control power within this center-of-gravity range limited the approach to 1g stalls which was characterized by mild instability roll-off and normal response to recovery control.

2. Throughout the speed range, typical swept-wing instability and buffet characteristics occurred at lower normal-force coefficients than with tail-on airplanes of similar sweep.

3. At high speeds the X-4 characteristics deteriorated as follows:

(a) At Mach numbers above 0.76 a residual yawing and rolling motion persisted at all times.

(b) At Mach numbers above 0.75 loss of total elevon effectiveness with speed and acceleration severely restricted maneuverability and maximum attainable lift.

(c) At Mach numbers above 0.85 elevon effectiveness began to decline rapidly in rolling maneuvers.

(d) At a Mach number of 0.88 the yawing and rolling coupled with the longitudinal motions resulting in persistent oscillations about three axes.

(e) At a Mach number of 0.90 a high-frequency short-period longitudinal oscillation appeared at normal acceleration greater than 1g.

(f) At Mach numbers above 0.90 elevon effectiveness had virtually disappeared, angles required for trim in level flight were high and maneuverability was only slight. Also, at Mach numbers above 0.90 the lateral-directional oscillation diverged to unsafe values. The tests were limited by the lack of control power to trim and maneuver and the divergent oscillation.

High-Speed Flight Station,
National Advisory Committee for Aeronautics,
Edwards, Calif., June 24, 1954.

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TABLE I.- PHYSICAL CHARACTERISTICS OF NORTHROP X-4 AIRPLANE

Engines (two)	Westinghouse J-30-WE-7-9
Rating (each), static thrust at sea level, lb	1,600
Airplane weight:	
Maximum (238 gal fuel), lb	7,820
Minimum (10 gal trapped fuel), lb	6,452
Wing loading:	
Maximum, lb/sq ft	39.1
Minimum, lb/sq ft	32.2
Center-of-gravity travel:	
Gear up, full load, percent M.A.C.	18.3
Gear up, post flight, percent M.A.C.	16.3
Gear down, full load, percent M.A.C.	18.6
Gear down, post flight, percent M.A.C.	16.7
Height, overall, ft	14.83
Length, overall, ft	23.25
Wing:	
Area, sq ft	200
Span, ft	26.83
Airfoil section	NACA 0010-64
Mean aerodynamic chord, ft	7.81
Aspect ratio	3.6
Root chord, ft	10.25
Tip chord, ft	4.67
Taper ratio	2.2:1
Sweepback (leading edge), deg	41.57
Dihedral (chord plane), deg	0
Wing boundary-layer fences:	
Length, percent local chord	30.0
Height, percent local chord	5.0
Location, percent semispan	90.0
Speed brakes (split flaps):	
Area, (plan view), sq ft	16.7
Span, ft	8.92
Chord, percent wing chord	25
Travel, deg	±60

TABLE I.- PHYSICAL CHARACTERISTICS OF NORTHROP X-4 AIRPLANE - Concluded

Elevons:	
Area (total), sq ft	17.20
Span (two elevons), ft	15.45
Chord, percent wing chord	20
Movement:	
Up, deg	35
Down, deg	20
Operation	Hydraulic with electrical emergency
Vertical tail:	
Area, sq ft	16
Height, ft	5.96
Rudder:	
Area, sq ft	4.1
Span, ft	4.3
Travel, deg	±30
Operation	Direct

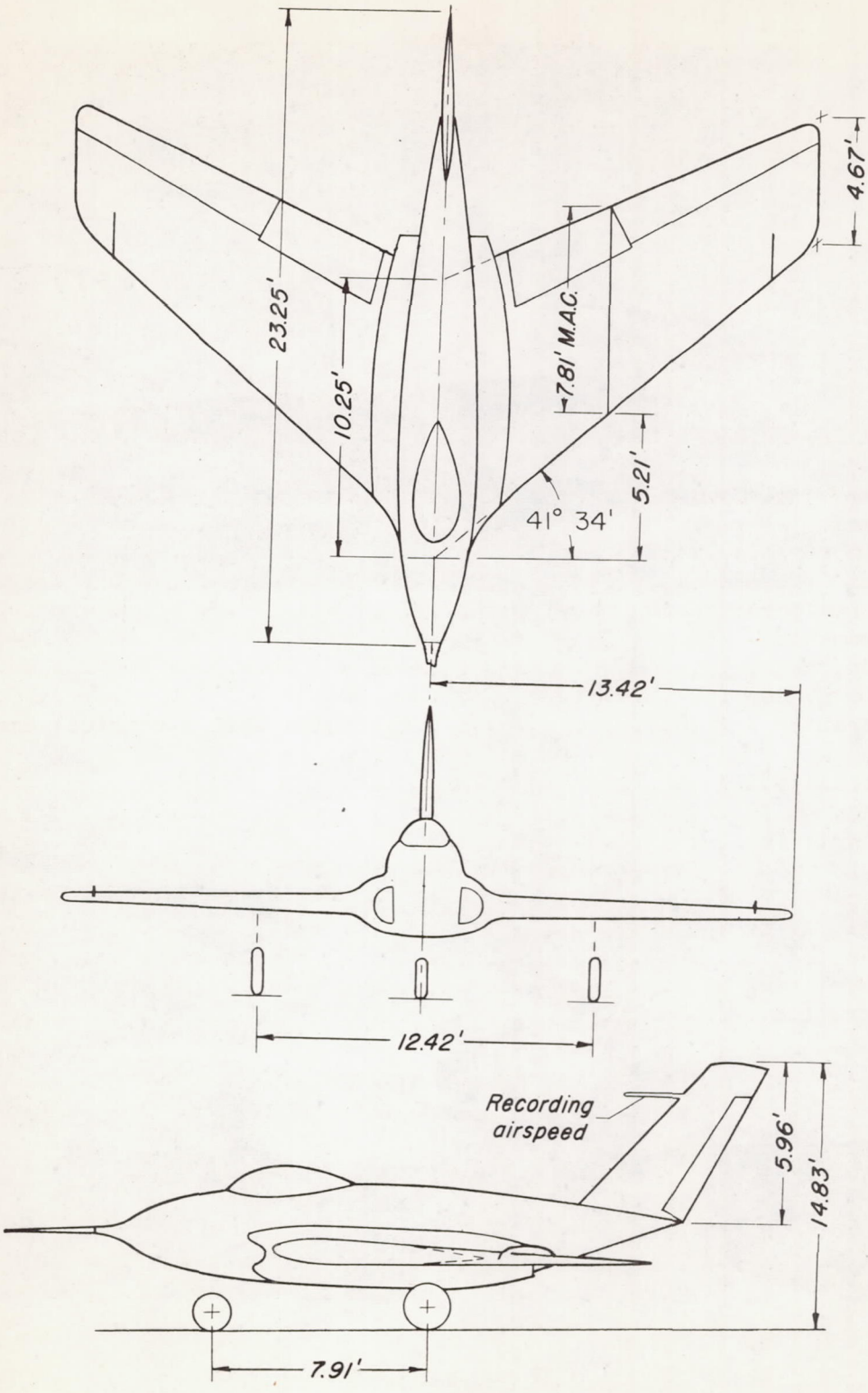
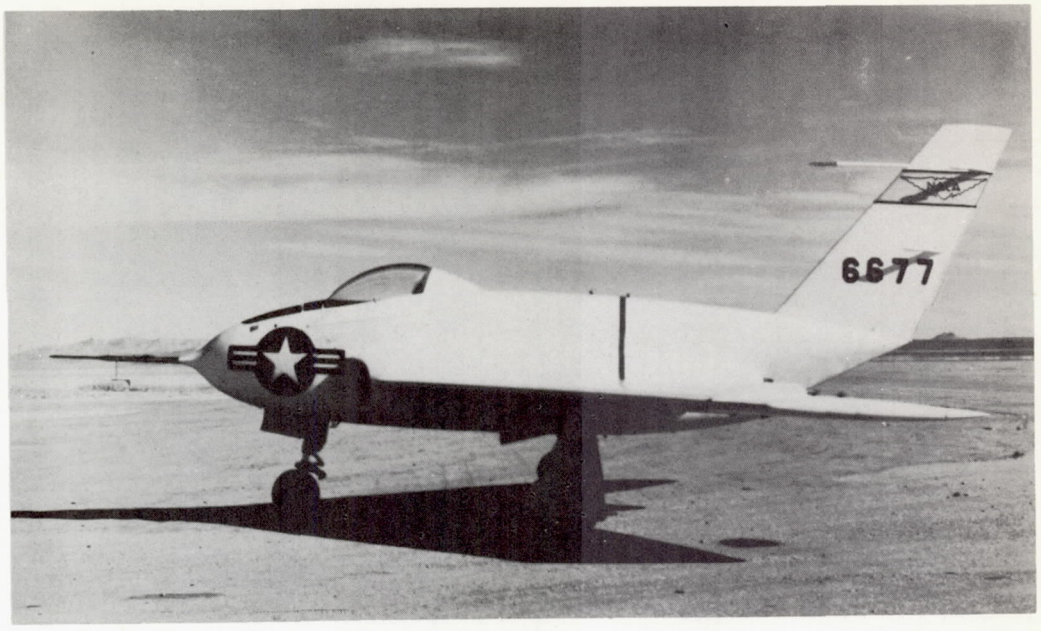


Figure 1.- Three-view drawing of the Northrop X-4 airplane.



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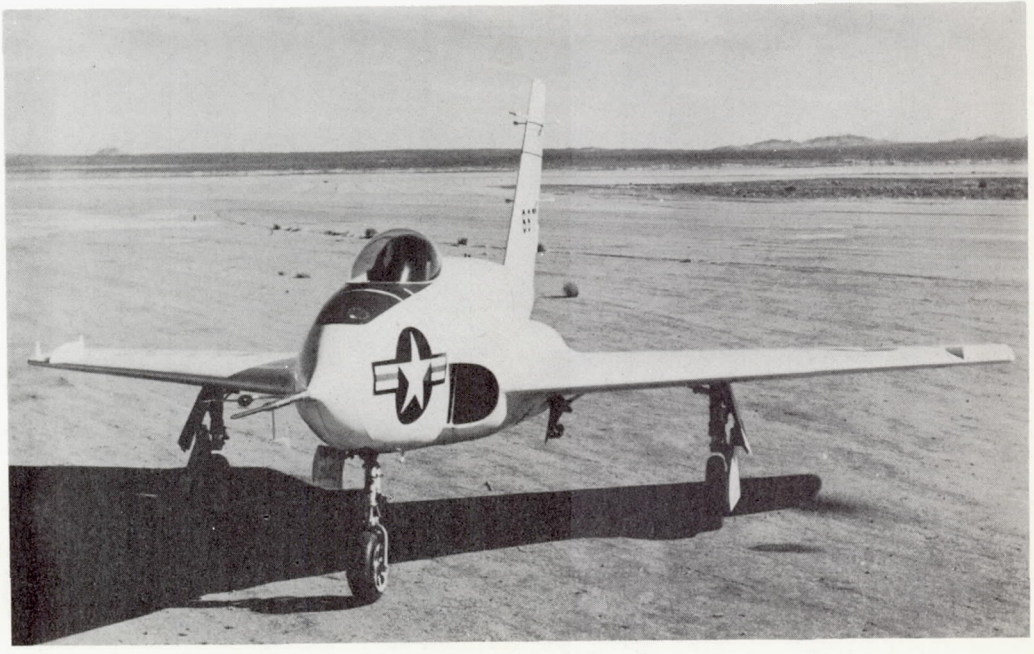
(a) Side view.



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(b) Three-quarter front view.

Figure 2.- Photographs of the Northrop X-4 airplane.

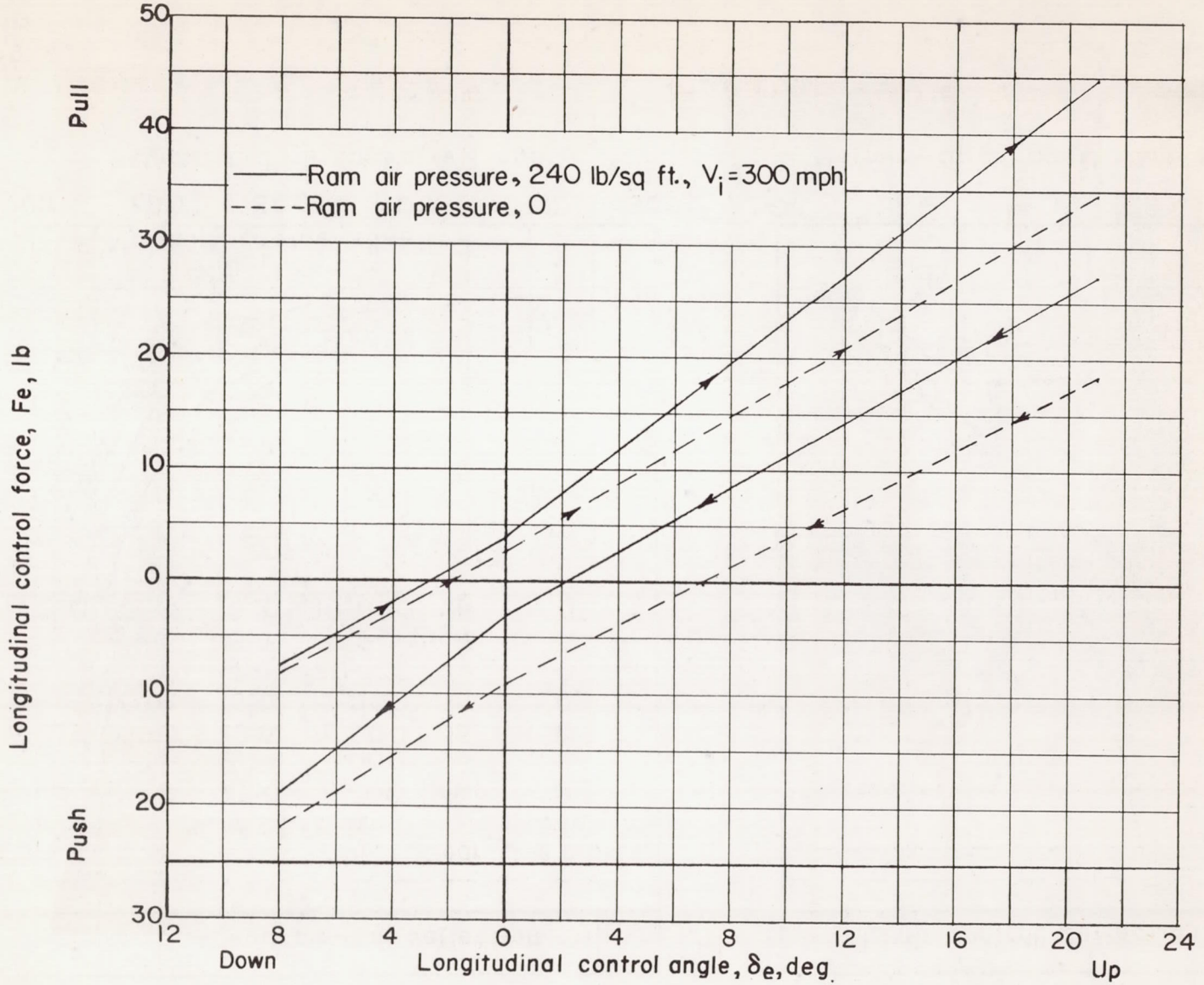

Figure 3.- Static friction envelopes of the elevon system.

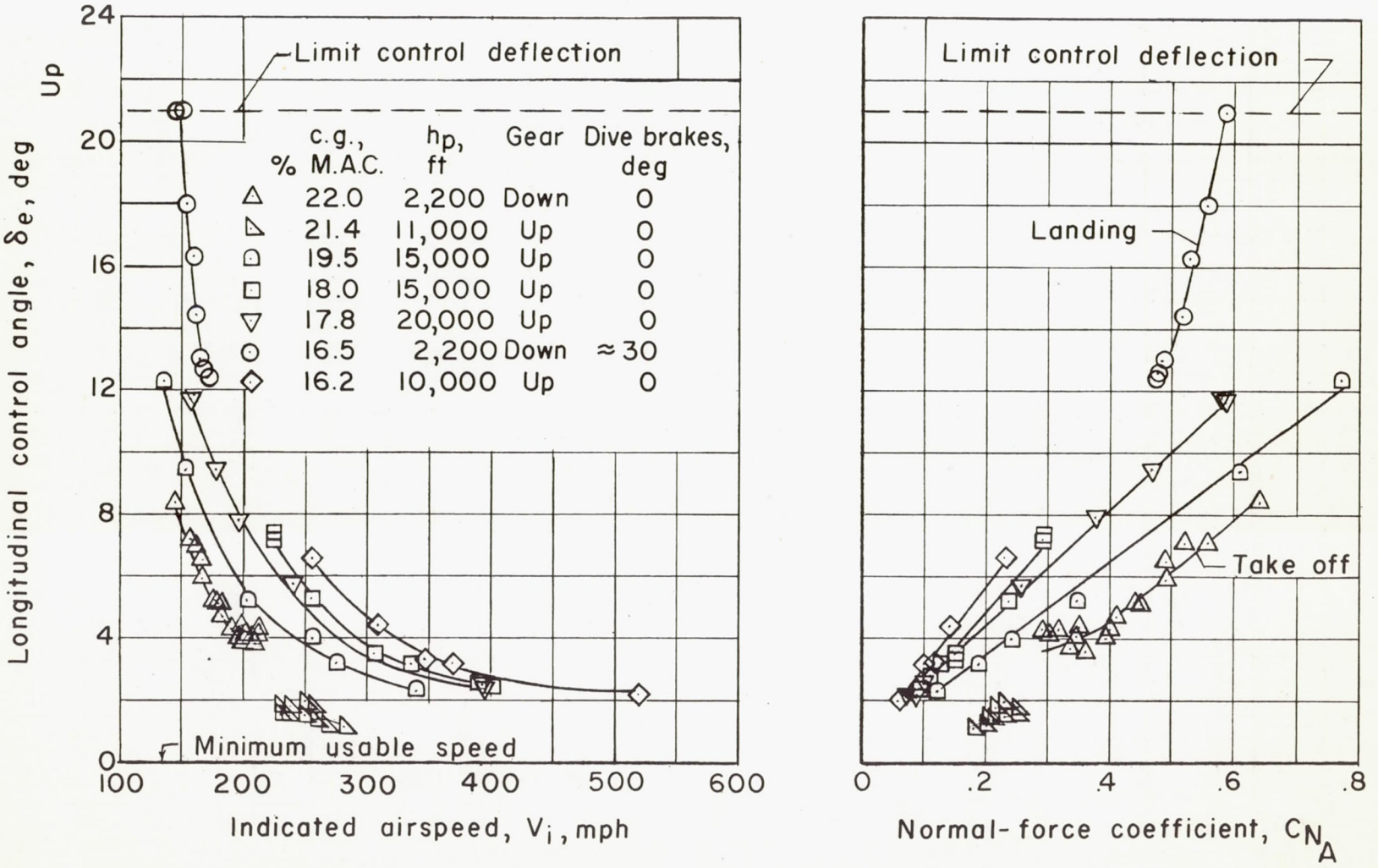

Figure 4.- Slow-speed stability and control characteristics in straight flight.

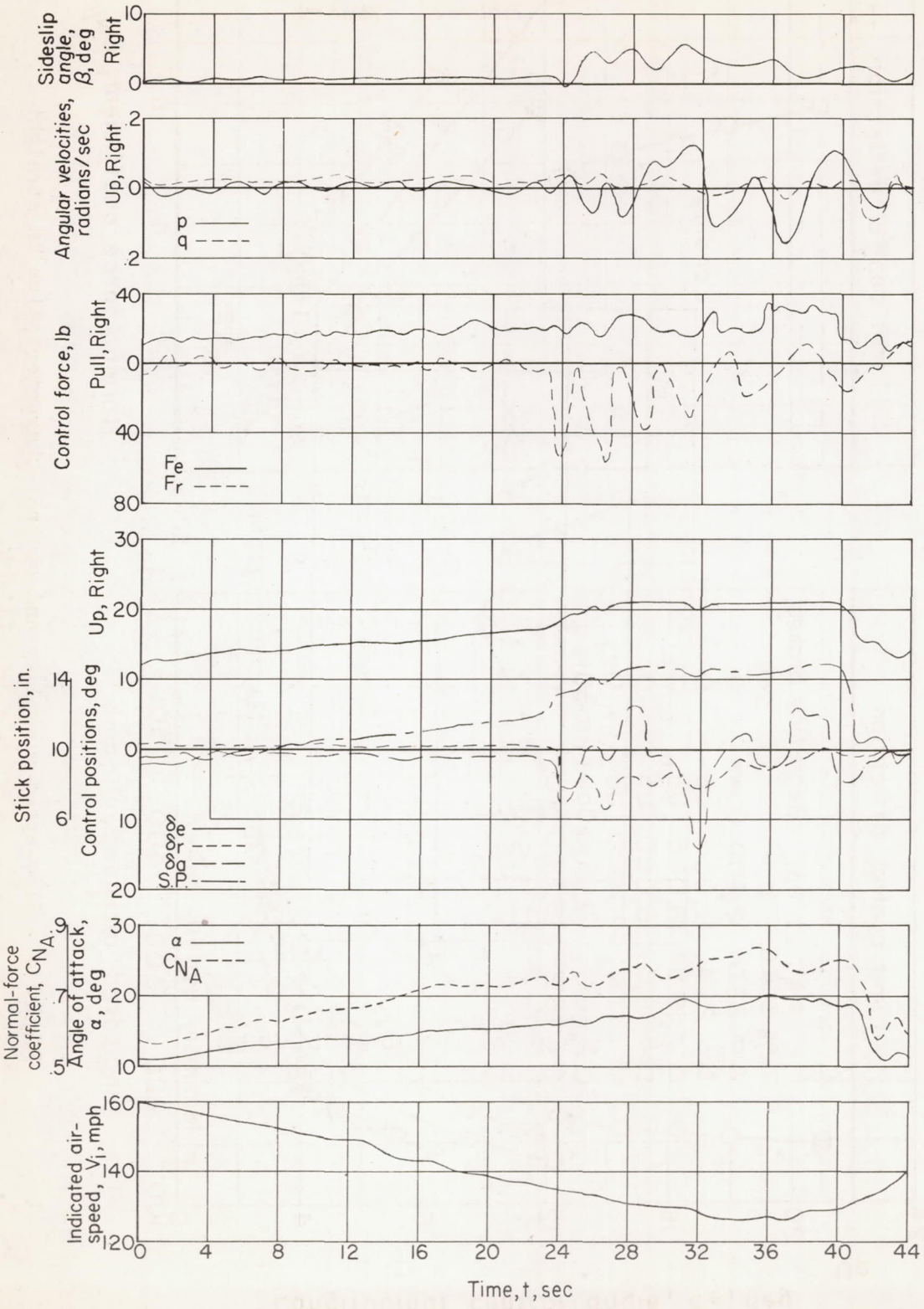

Figure 5.- Time histories of a straight flight stall, landing configuration. X-4 airplane.

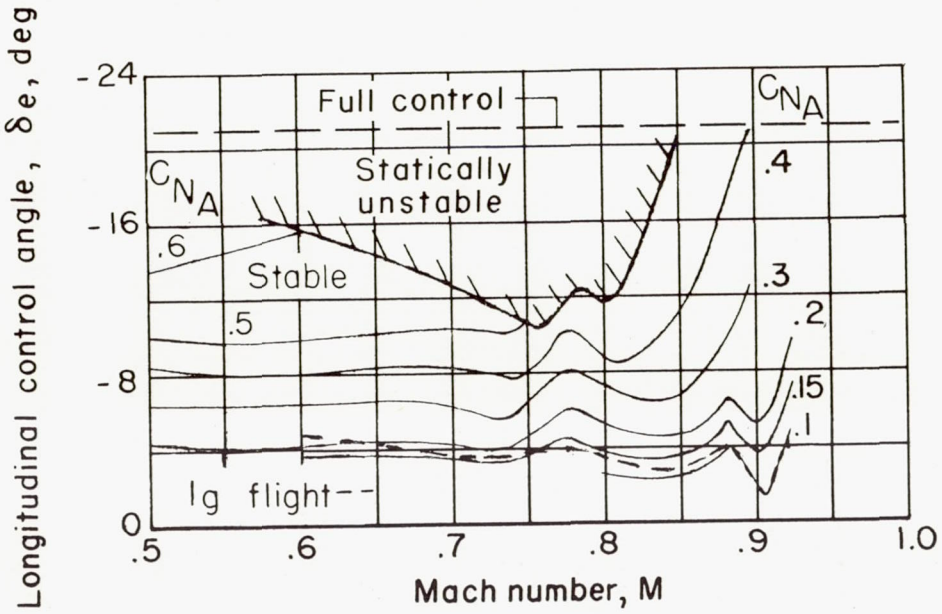

Figure 6.- Longitudinal trim characteristics. X-4 airplane; h_p = 30,000 feet.

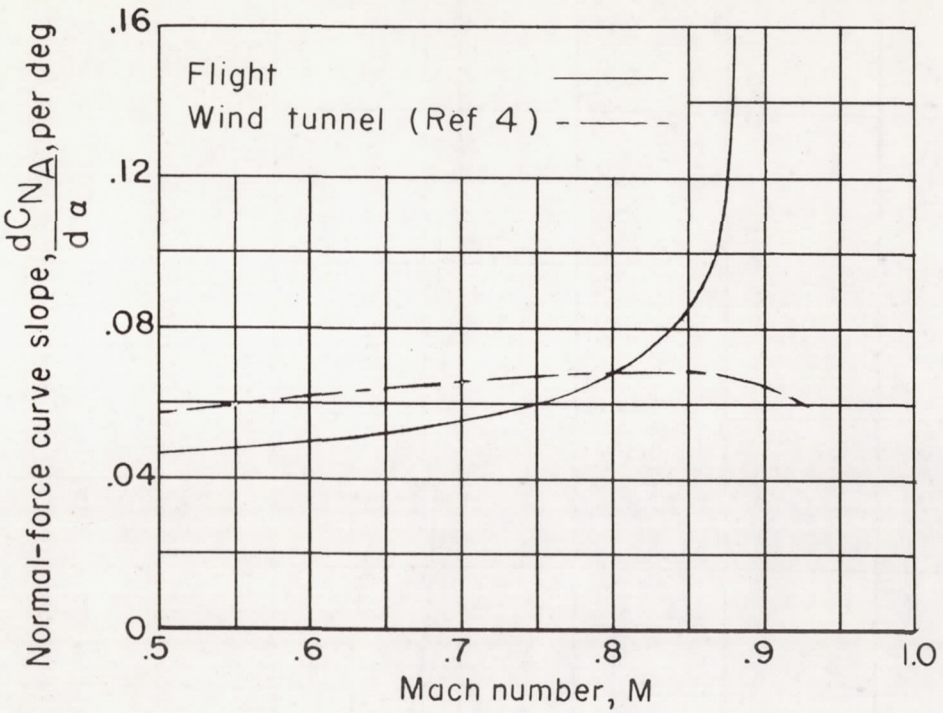

Figure 7.- Trimmed airplane normal-force curve slope, level flight C_{N_A}. X-4 airplane; h_p = 30,000 feet.

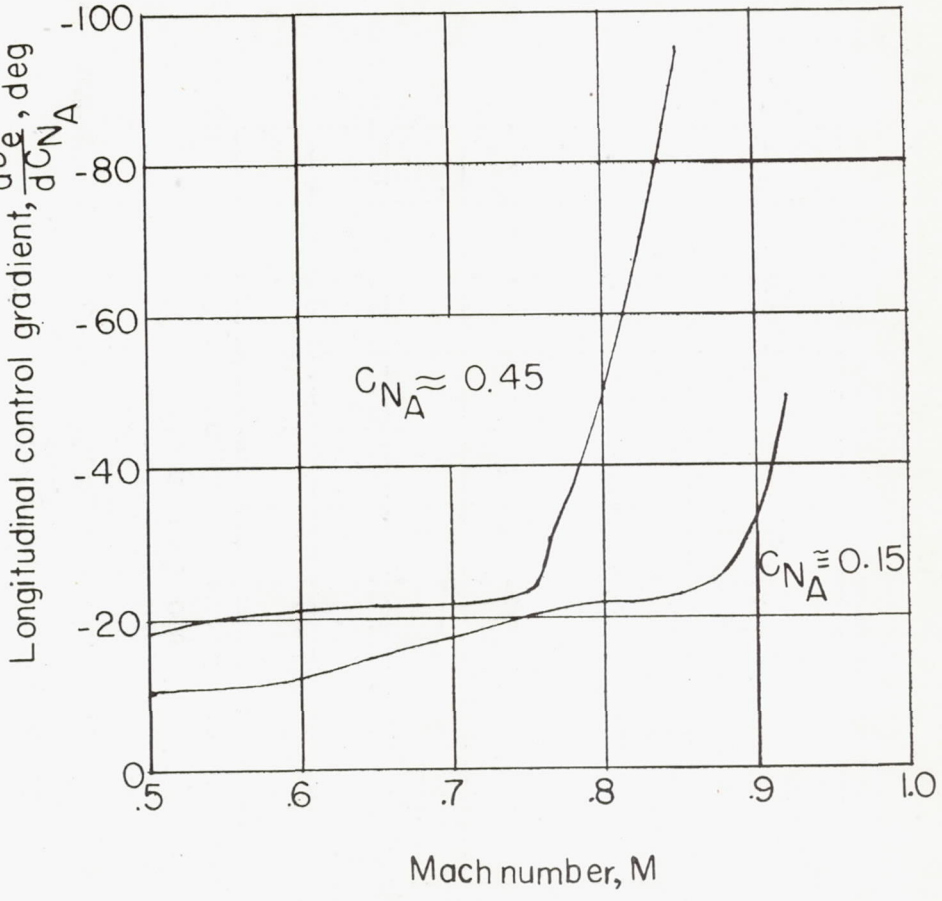

Figure 8.- Variation of elevon deflection with normal-force coefficient plotted against Mach number. X-4 airplane; h_p = 30,000 feet.

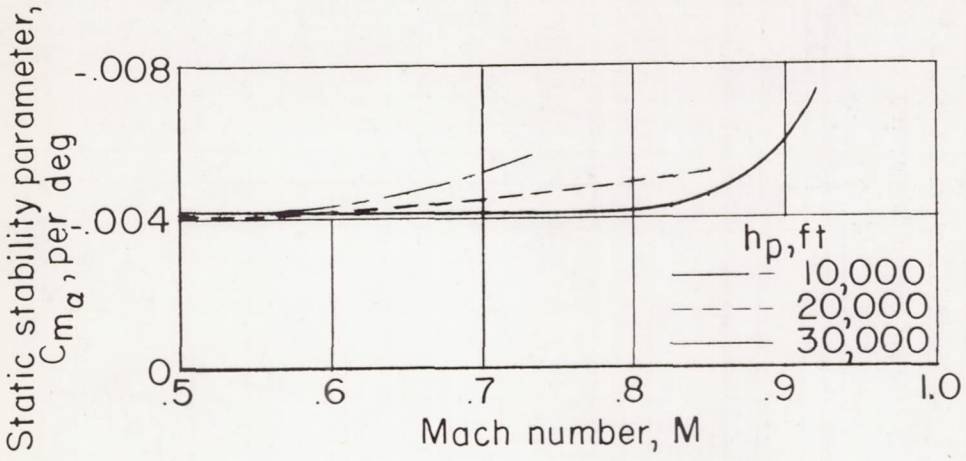

Figure 9.- Static stability variation with Mach number.

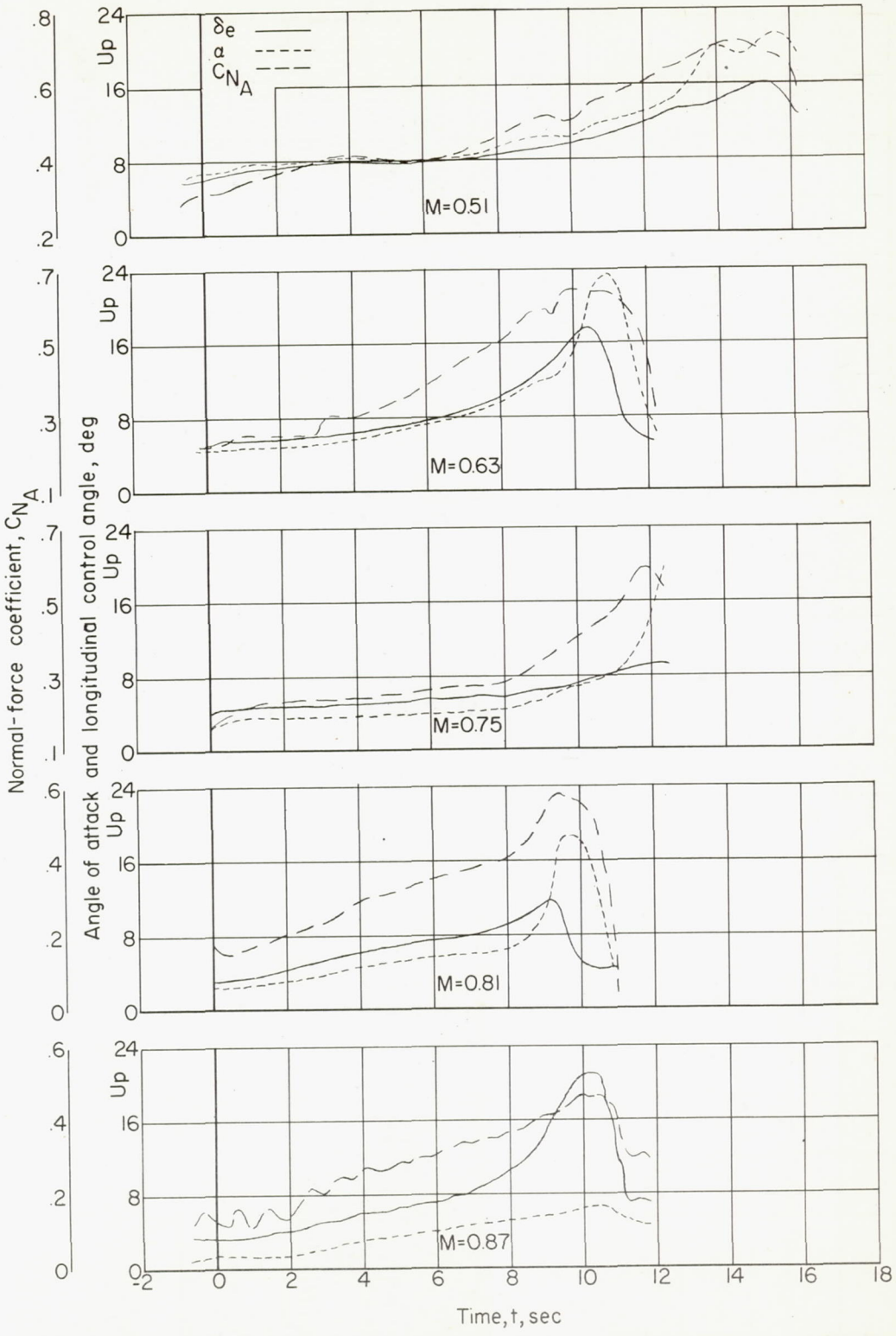

Figure 10.- Time histories of wind-up turns. X-4 airplane; h_p = 30,000 feet.

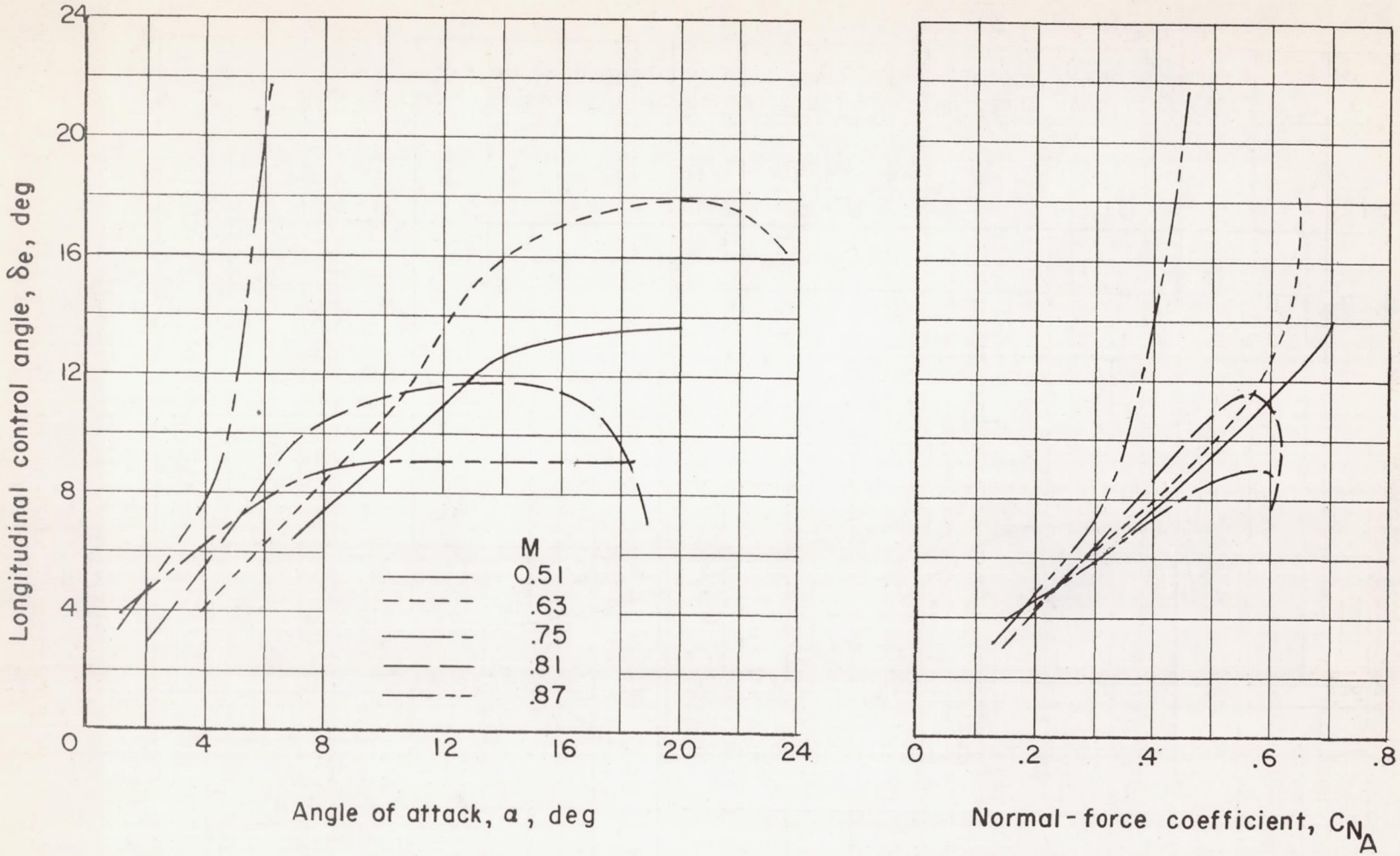

Figure 11.- Longitudinal stability characteristics in accelerated flight at 30,000 feet. X-4 airplane.

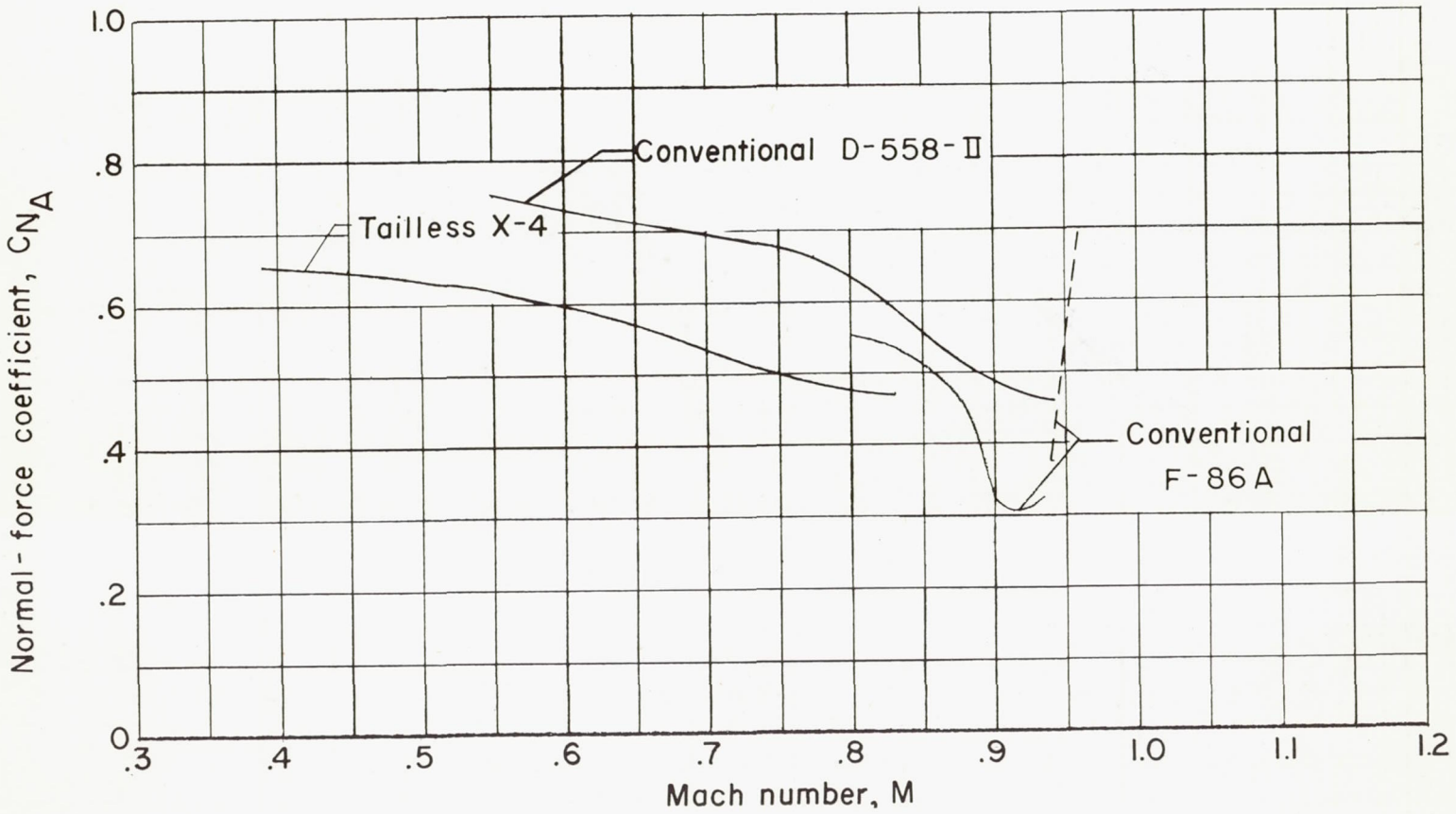

Figure 12.- Boundary for decreased static longitudinal stability for the X-4 and conventional airplanes. h_p = 30,000 feet.

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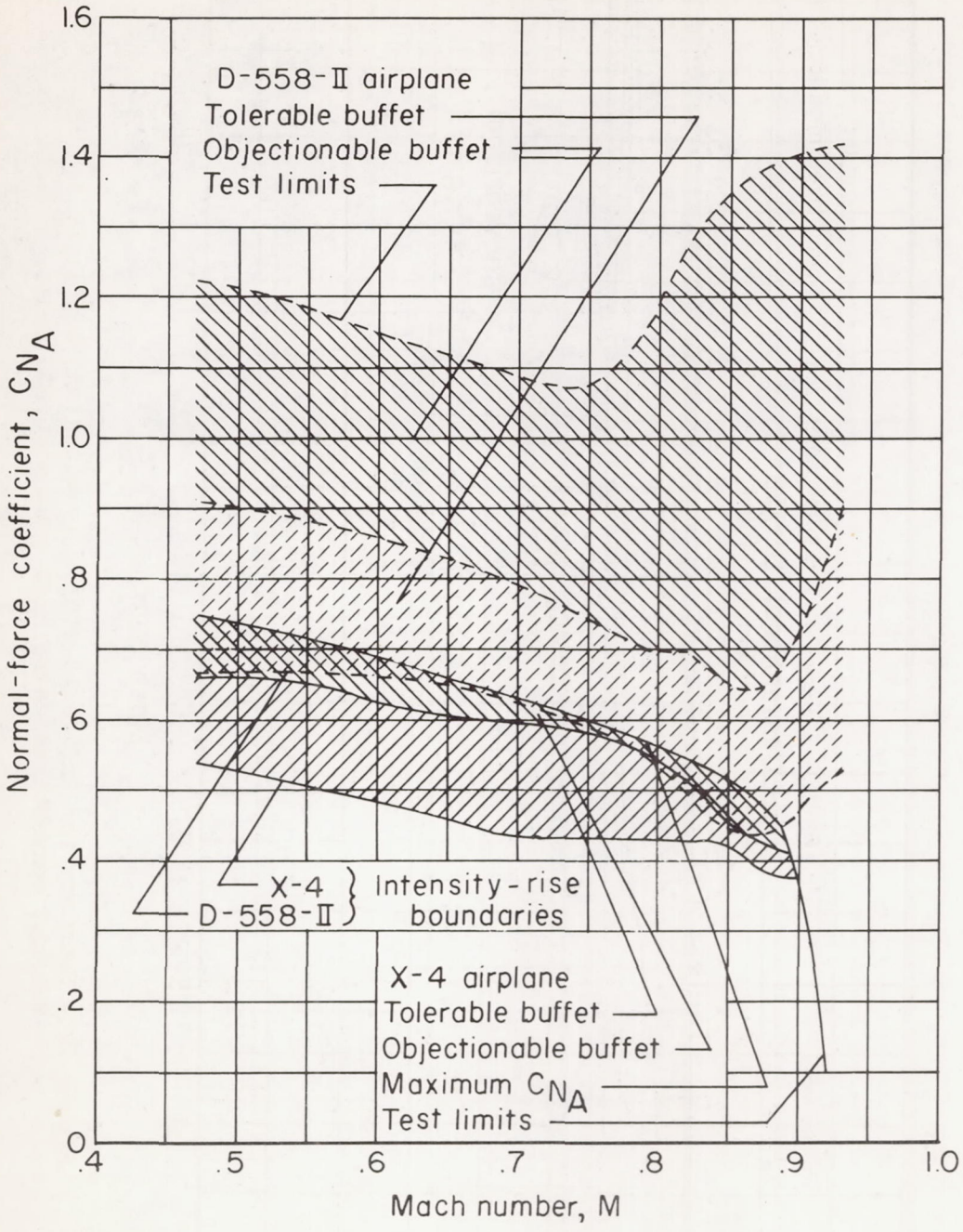
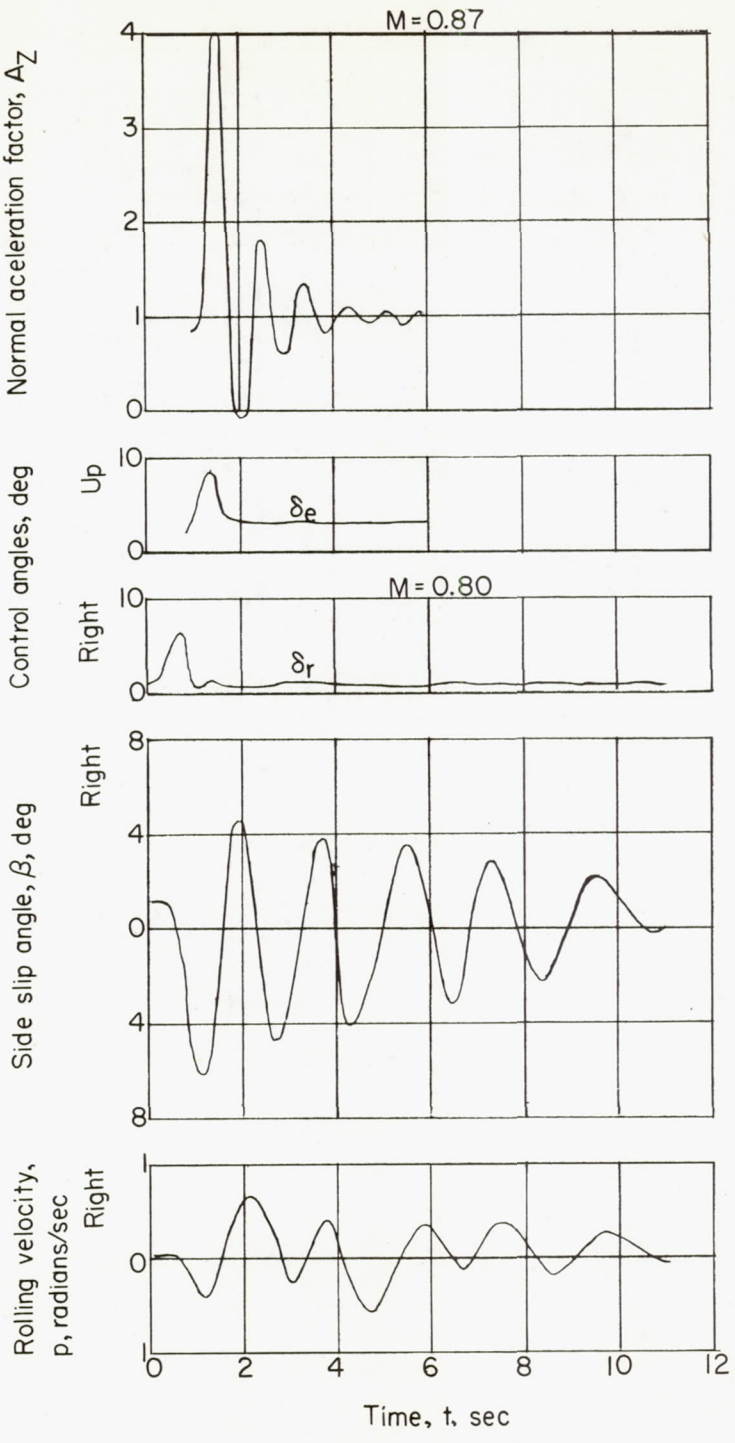
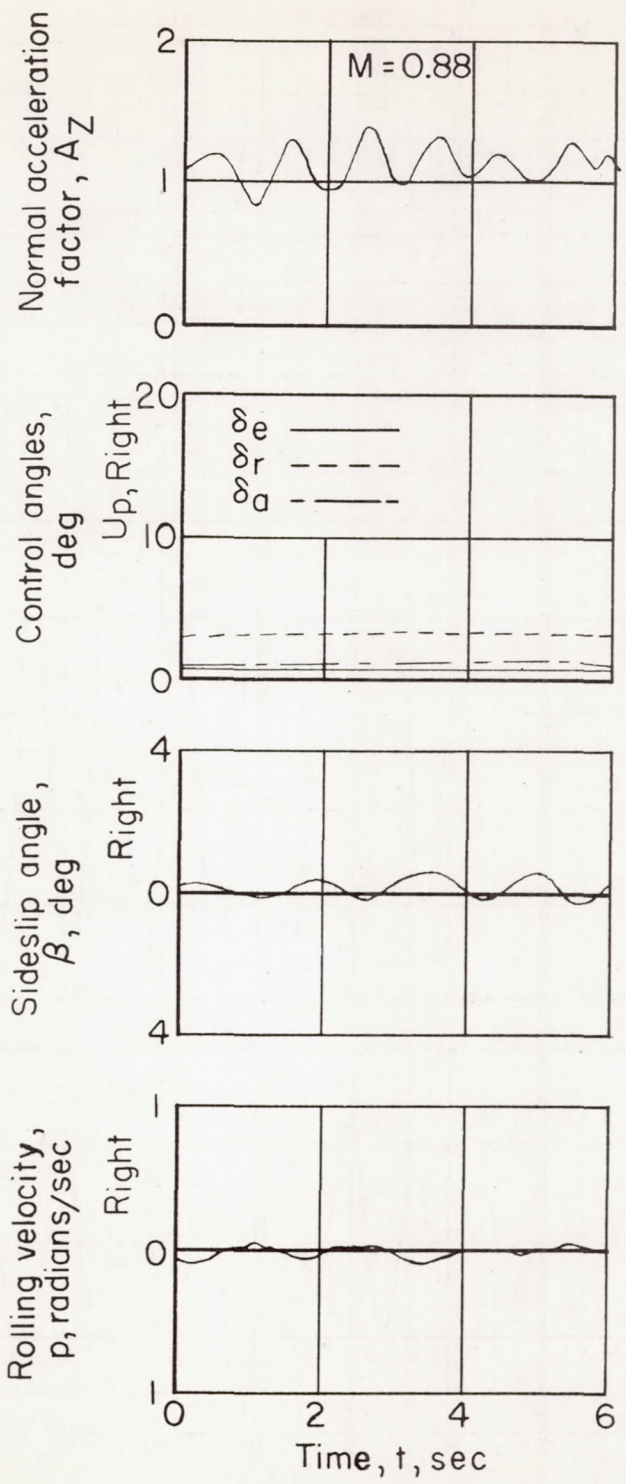


Figure 13.- Buffet characteristics of the X-4 airplane and a comparison with data obtained on the conventional D-558-II airplane.



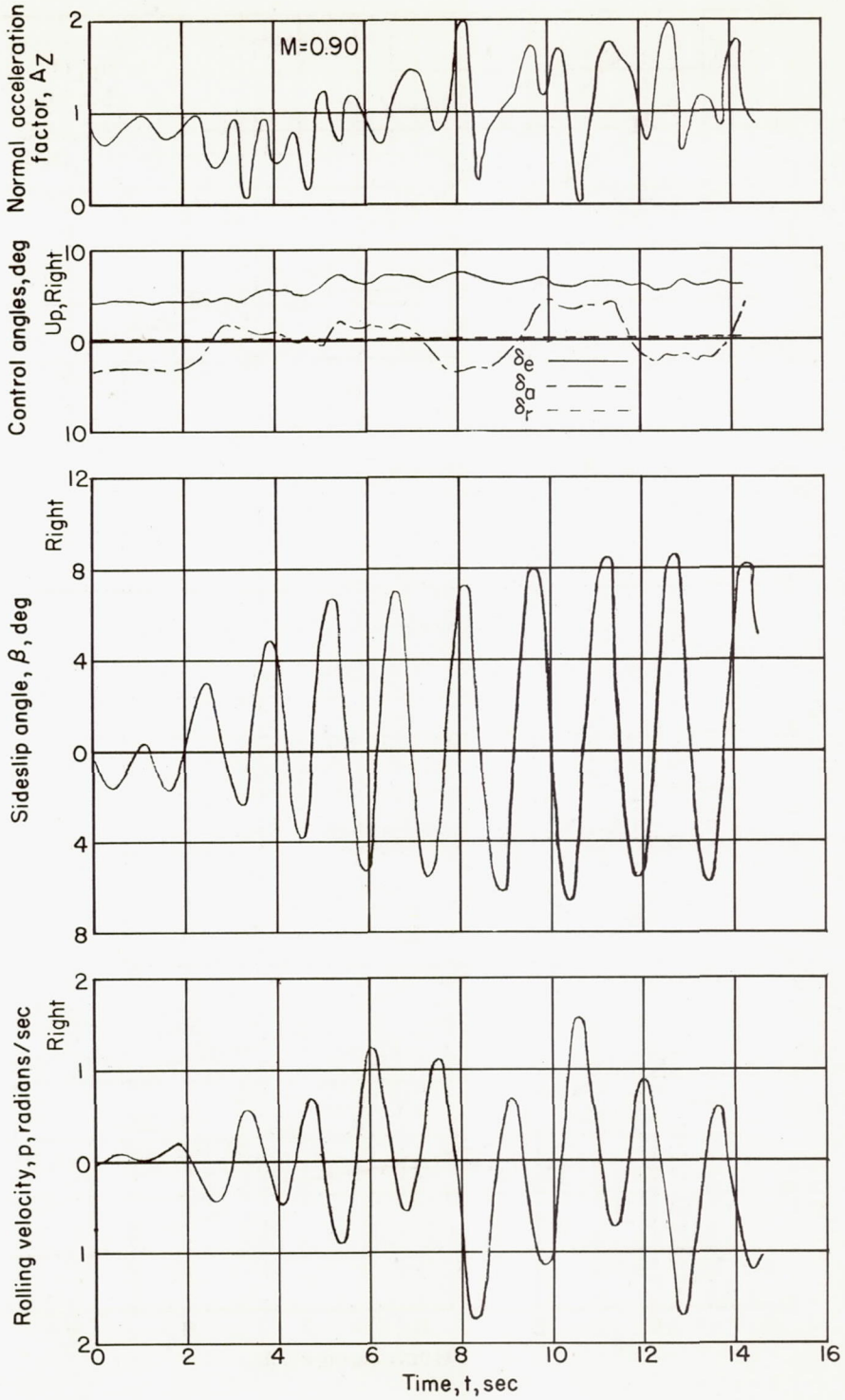
(a) Longitudinal oscillation at M = 0.87, lateral oscillation at M = 0.80.

Figure 14.- Time histories of longitudinal and lateral oscillations; h_p = 30,000 feet.



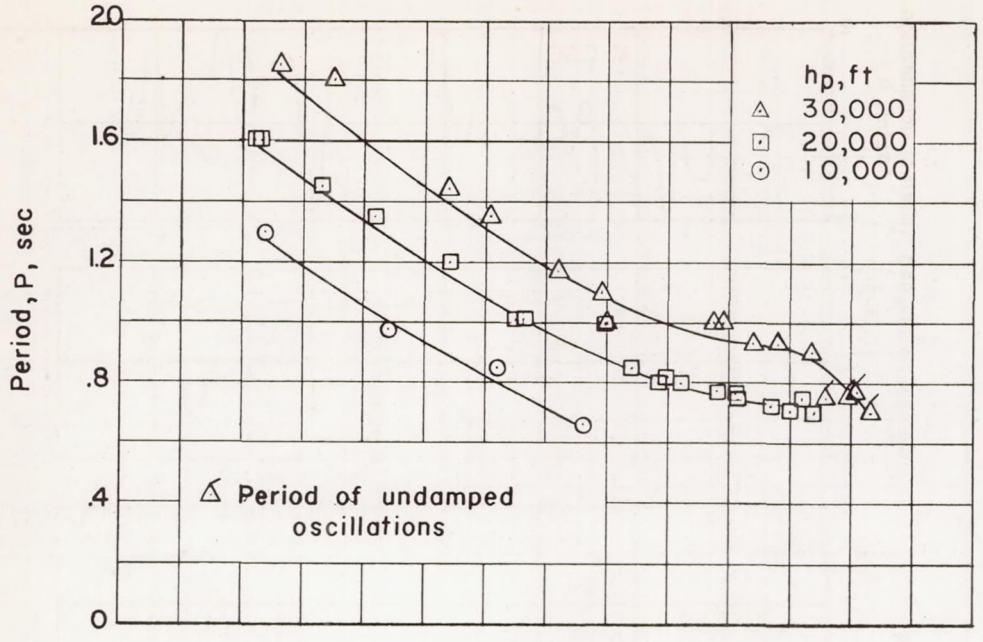
(b) M = 0.88.

Figure 14.- Continued.

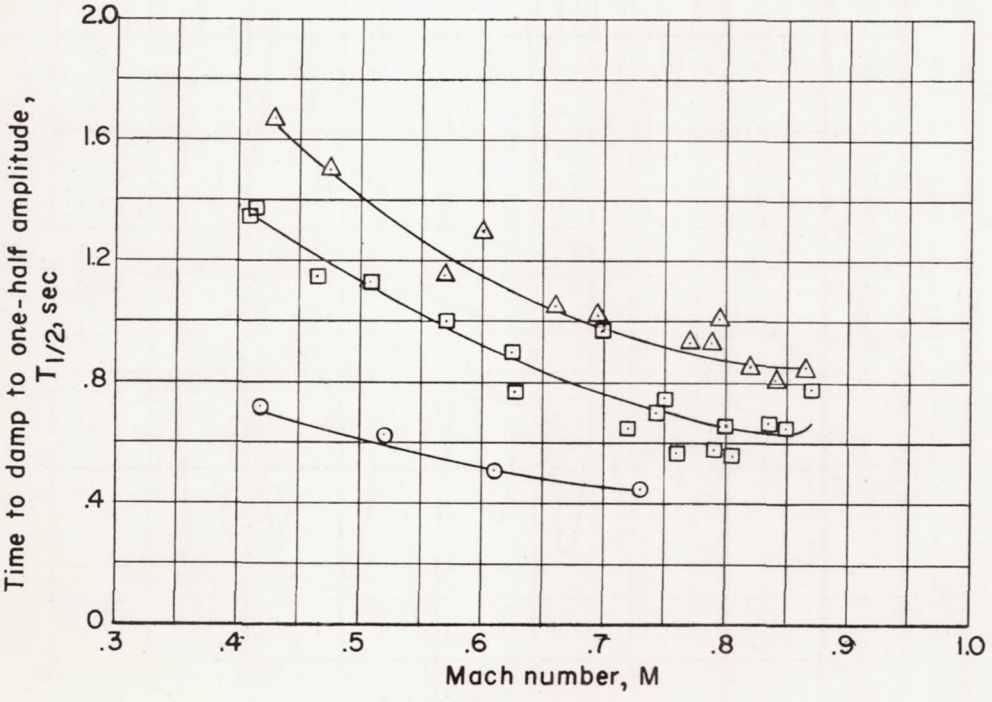


(c) M = 0.90.

Figure 14.- Concluded.

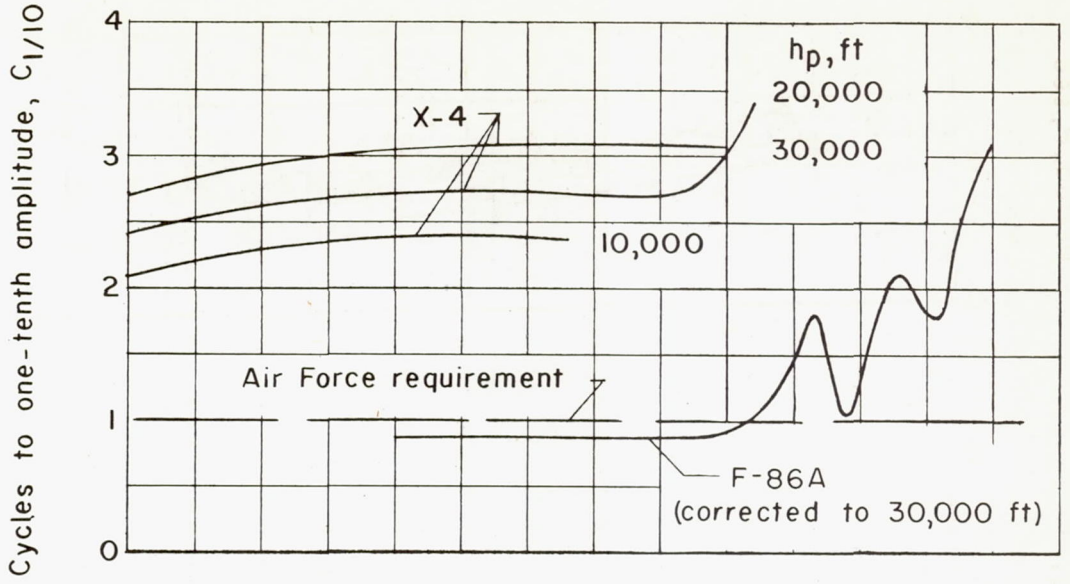


(a) Period.

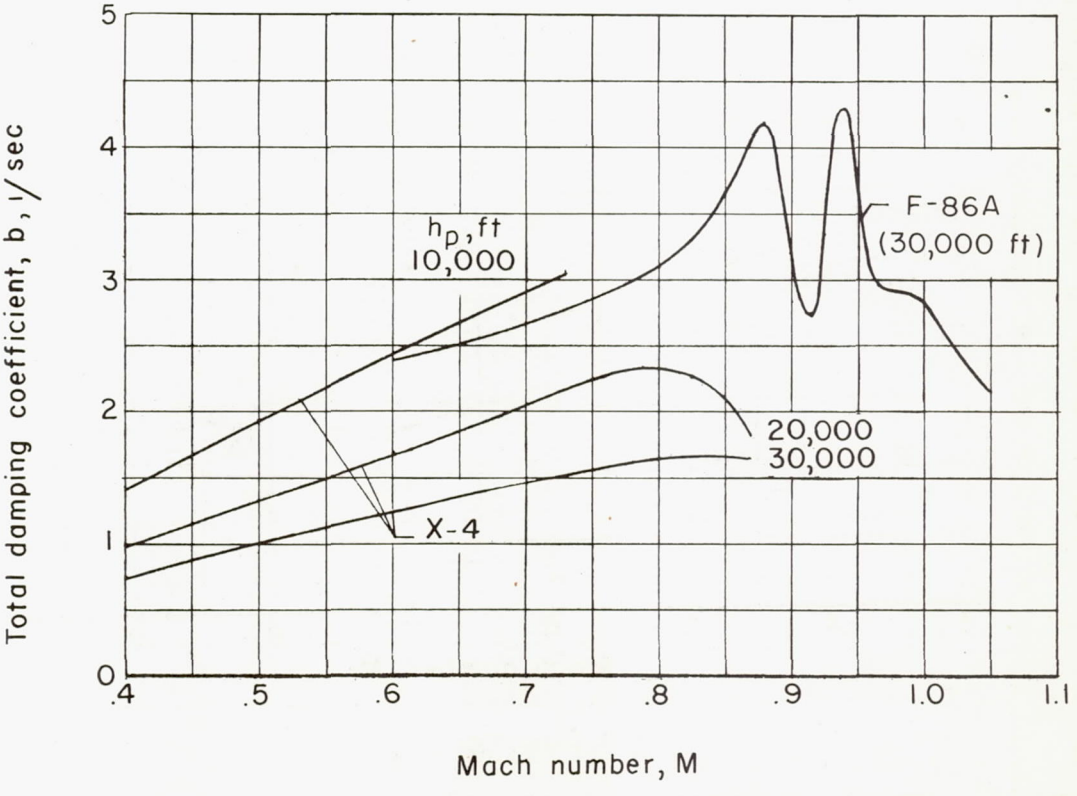


(b) Damping.

Figure 15.- Longitudinal period and damping characteristics.

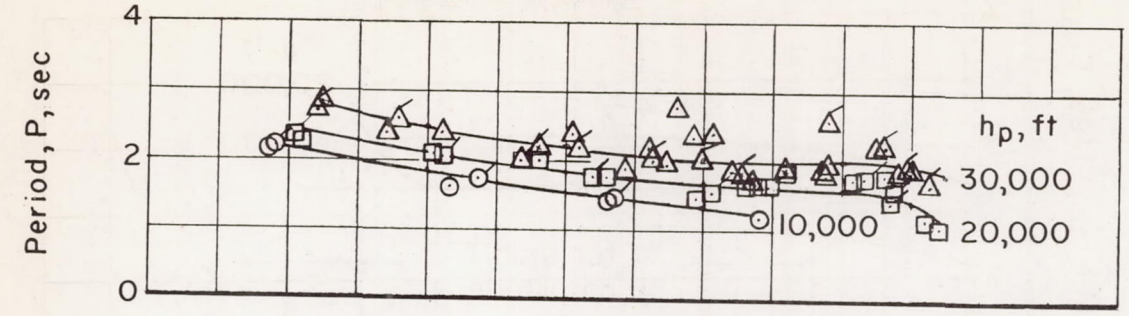


(a) Cycles to one-tenth amplitude.

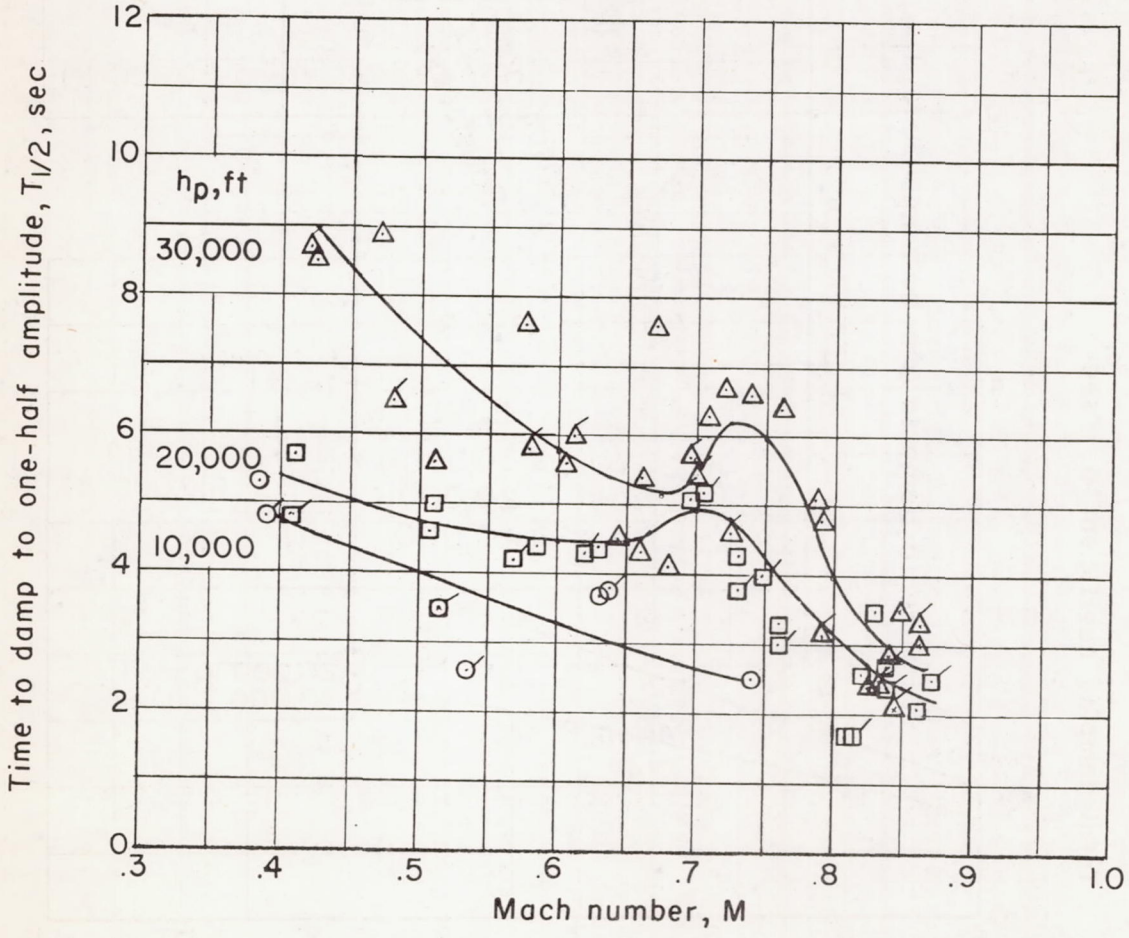


(b) Total damping coefficient.

Figure 16.- Longitudinal damping characteristics of the X-4 compared with the F-86A.



(a) Period.



(b) Damping.

Figure 17.- Period and damping characteristics of the lateral-directional oscillation. Flagged symbols denote free rudder.

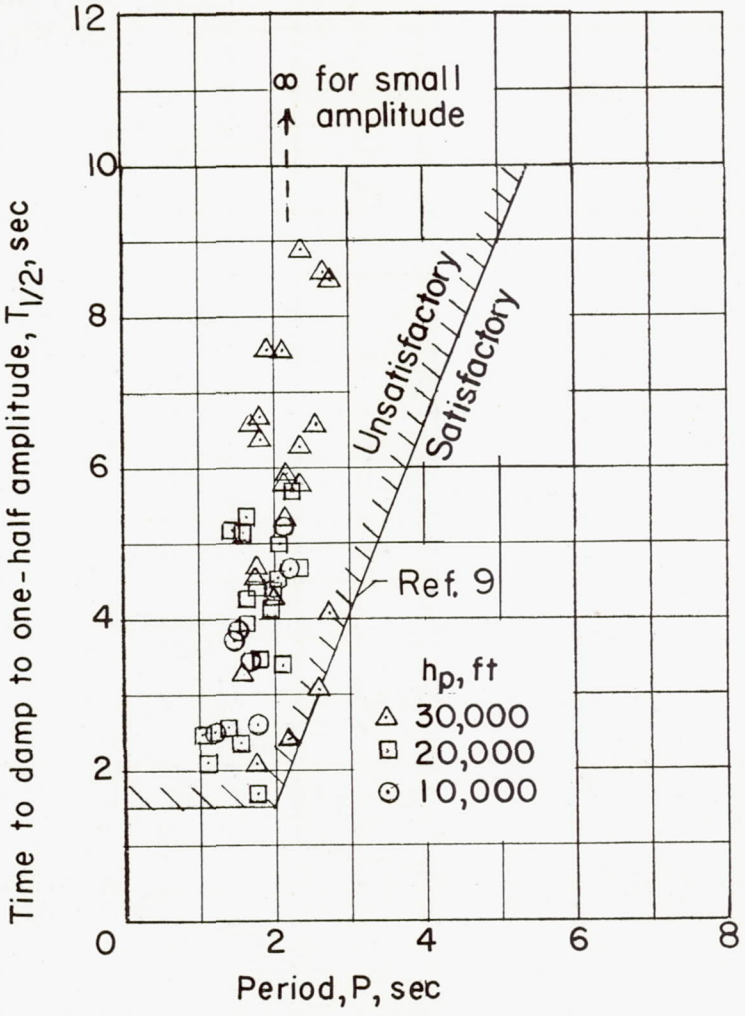


Figure 18.- Lateral-directional damping characteristics.

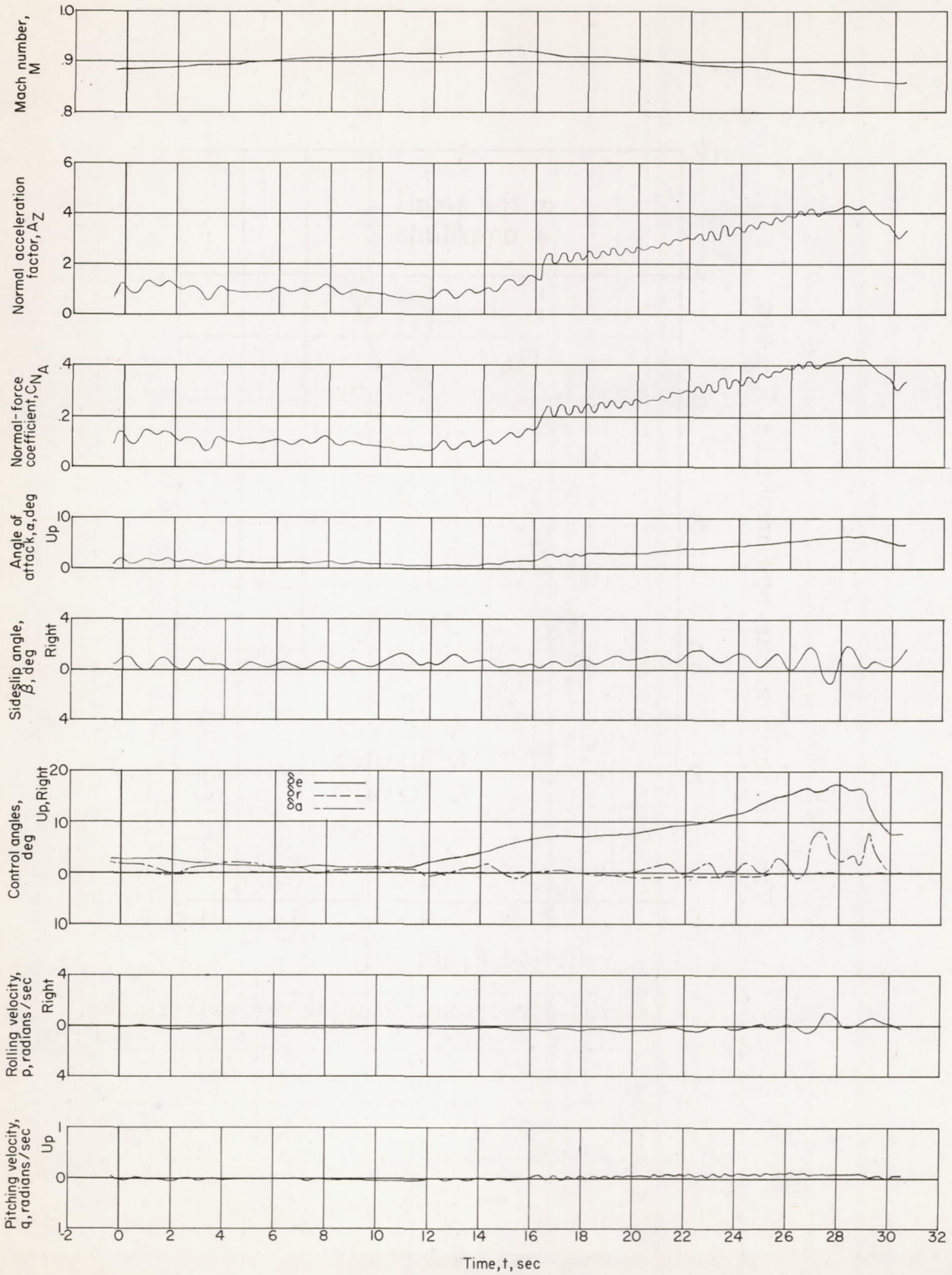
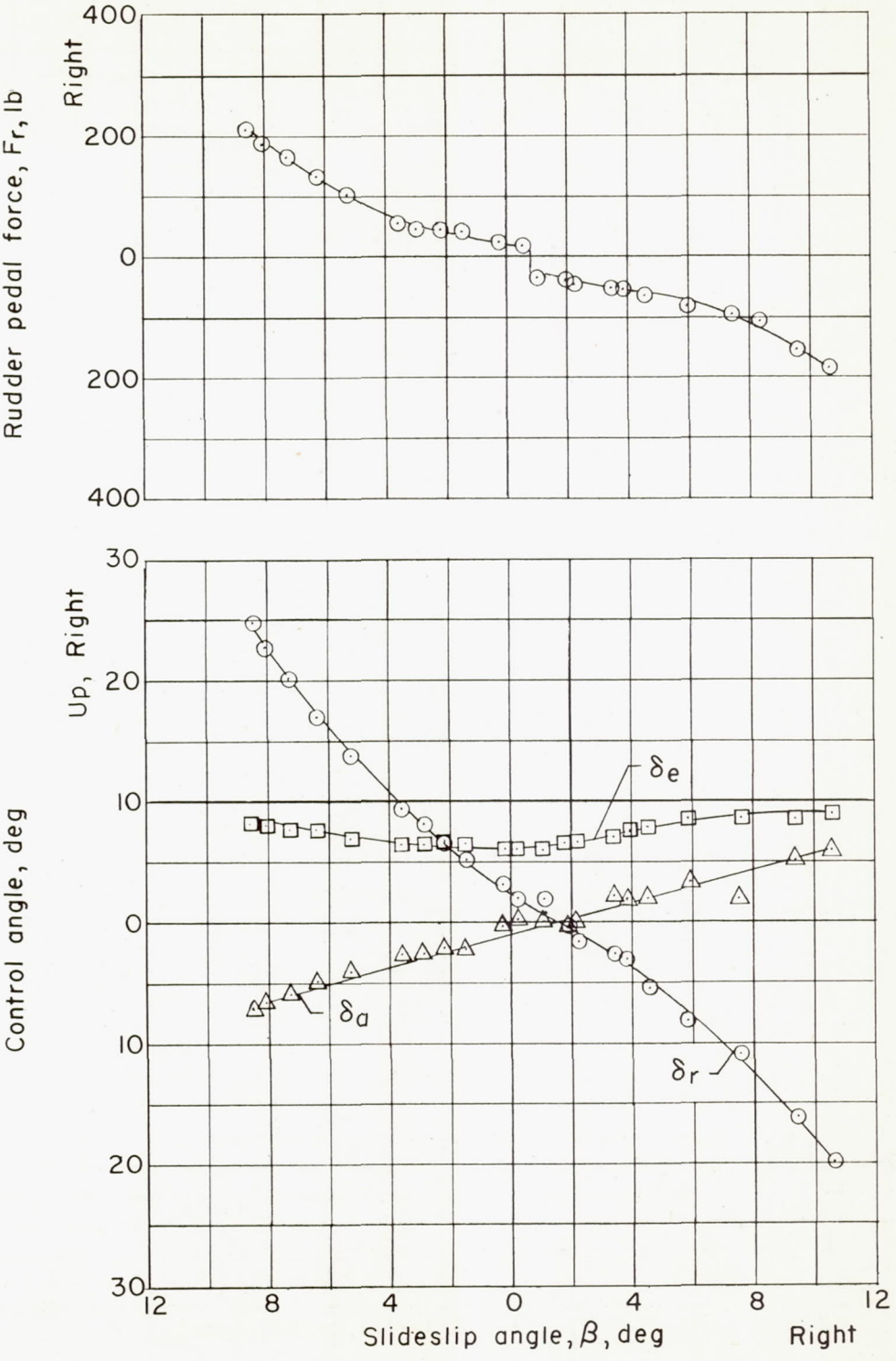
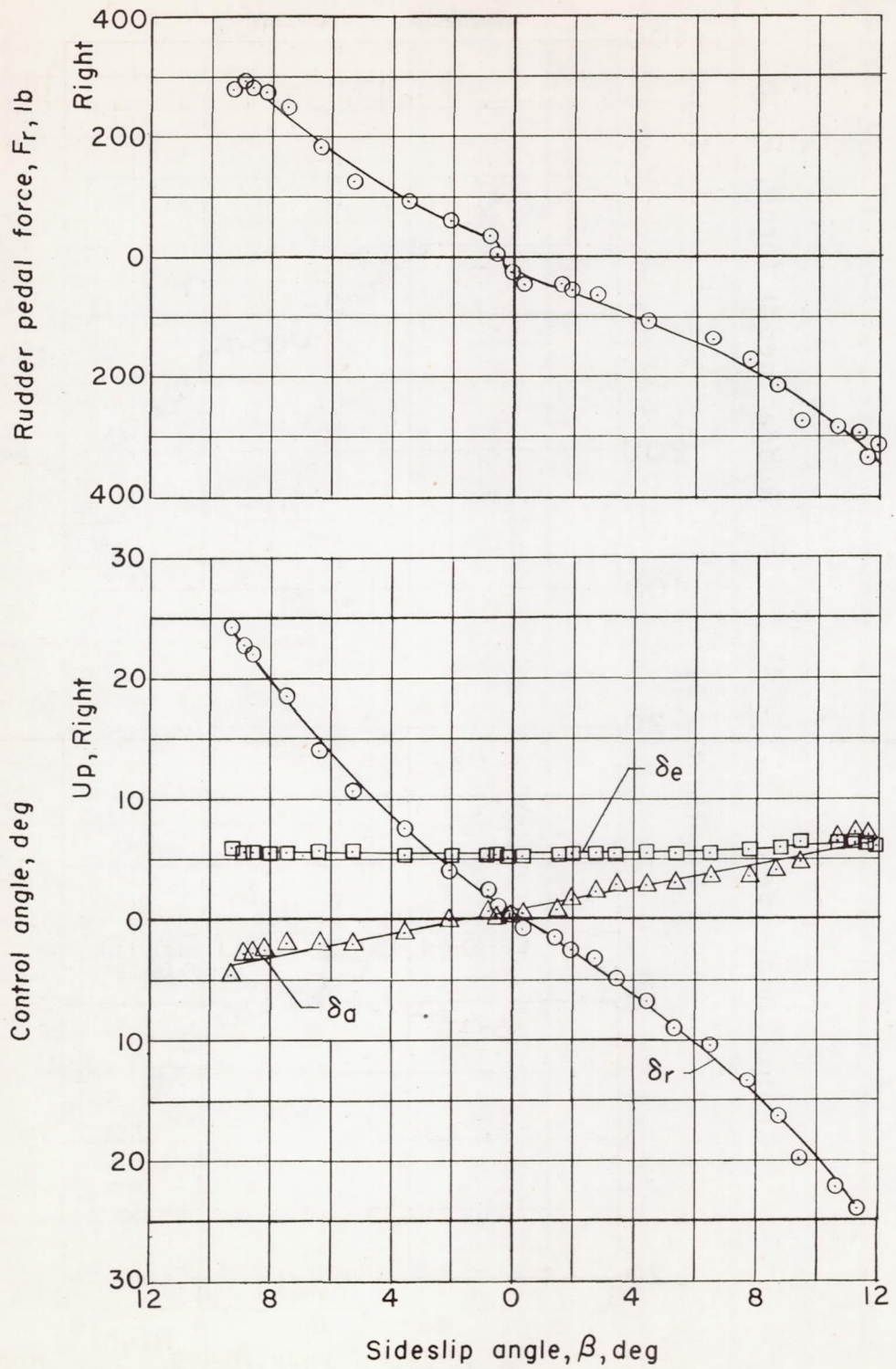


Figure 19.- Dynamic behavior variations with changing Mach number and changing normal acceleration; h_p = 30,000 feet.



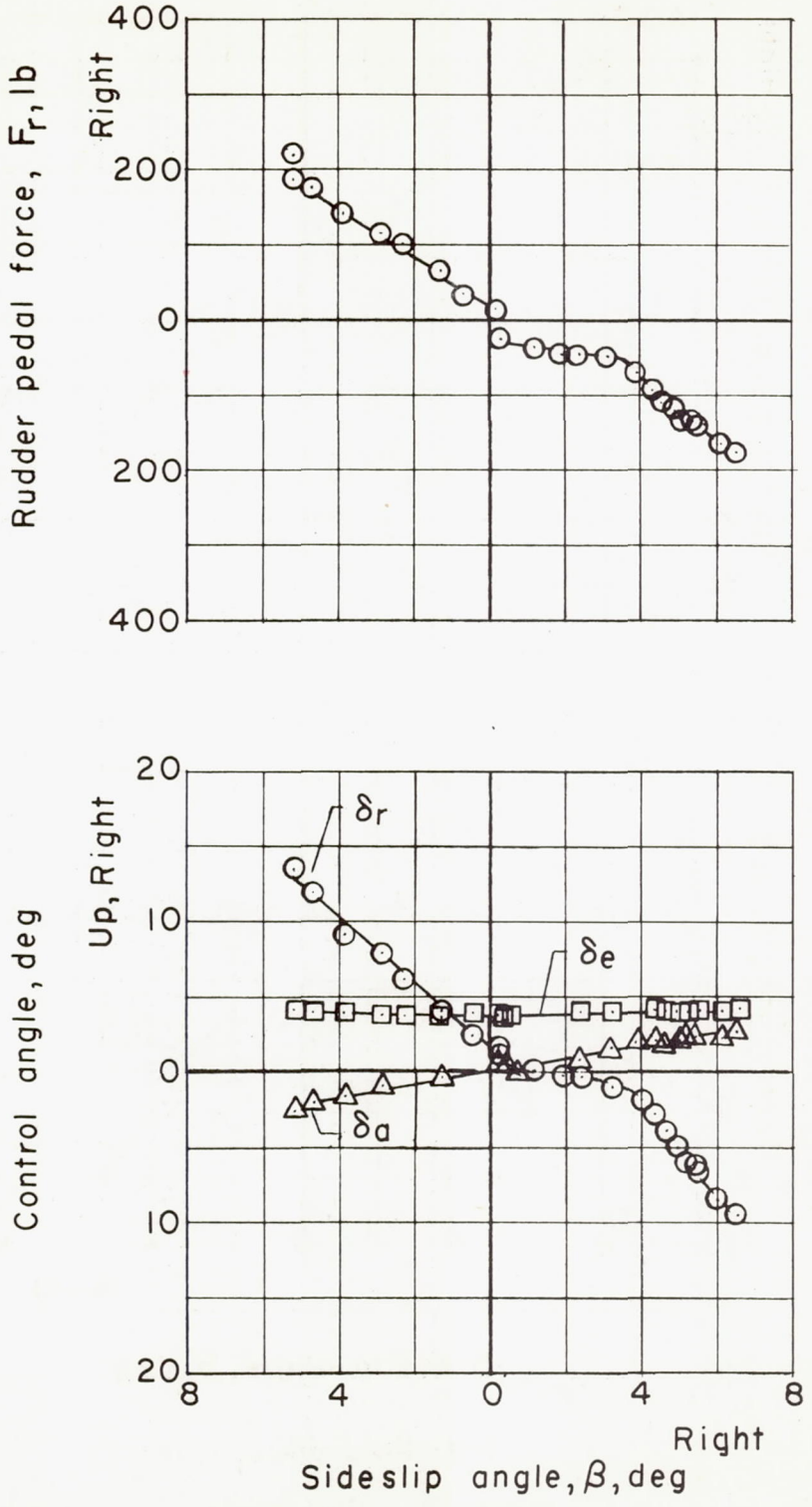
(a) M = 0.49.

Figure 20.- Steady sideslip characteristics at several values of Mach number. h_p = 30,000 feet.



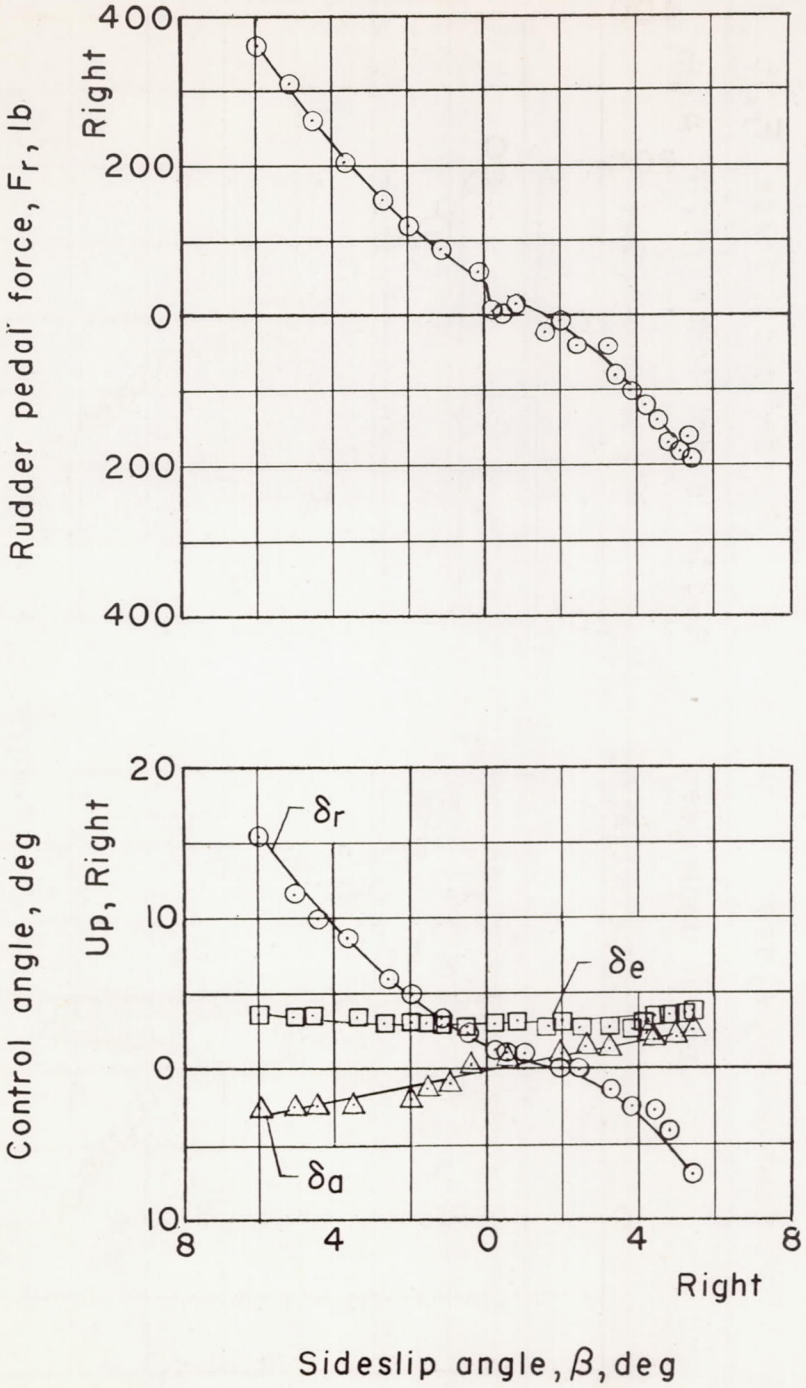
(b) M = 0.61.

Figure 20.- Continued.



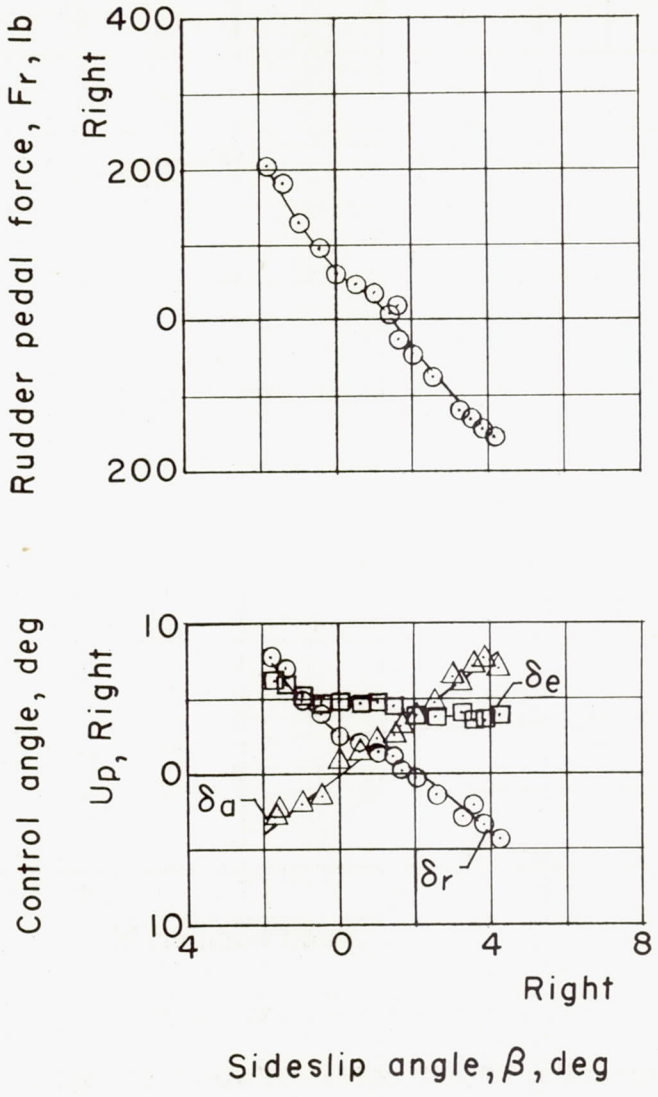
(c) M = 0.73.

Figure 20.- Continued.



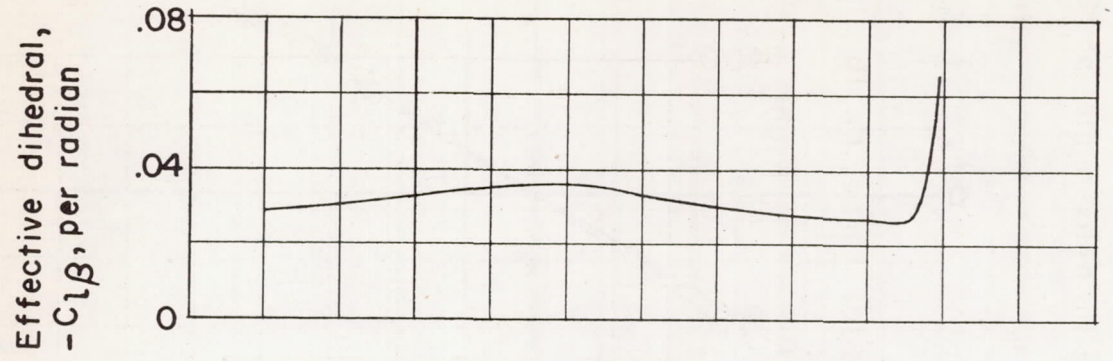
(d) M = 0.83.

Figure 20.- Continued.

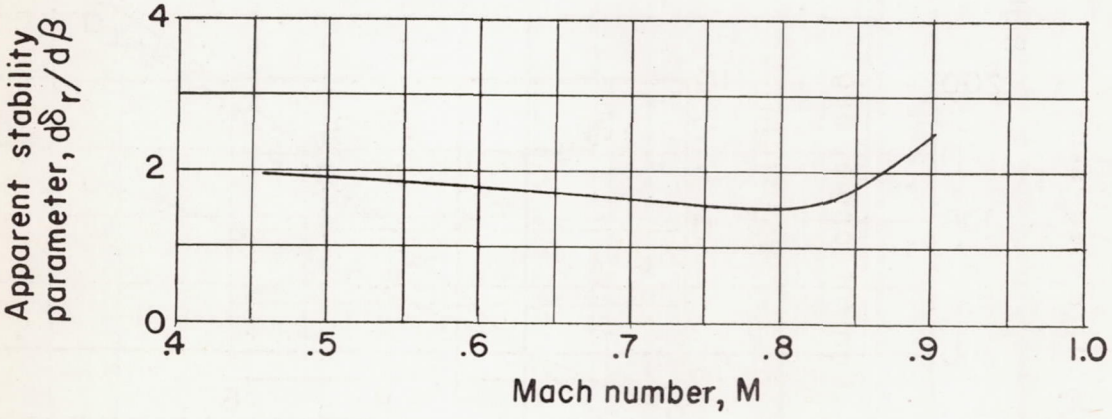


(e) M = 0.90.

Figure 20.- Concluded.



(b) Effective dihedral.



(a) Apparent stability parameter.

Figure 21.- Variation of effective dihedral and apparent directional stability parameters with Mach number; h_p = 30,000 feet.

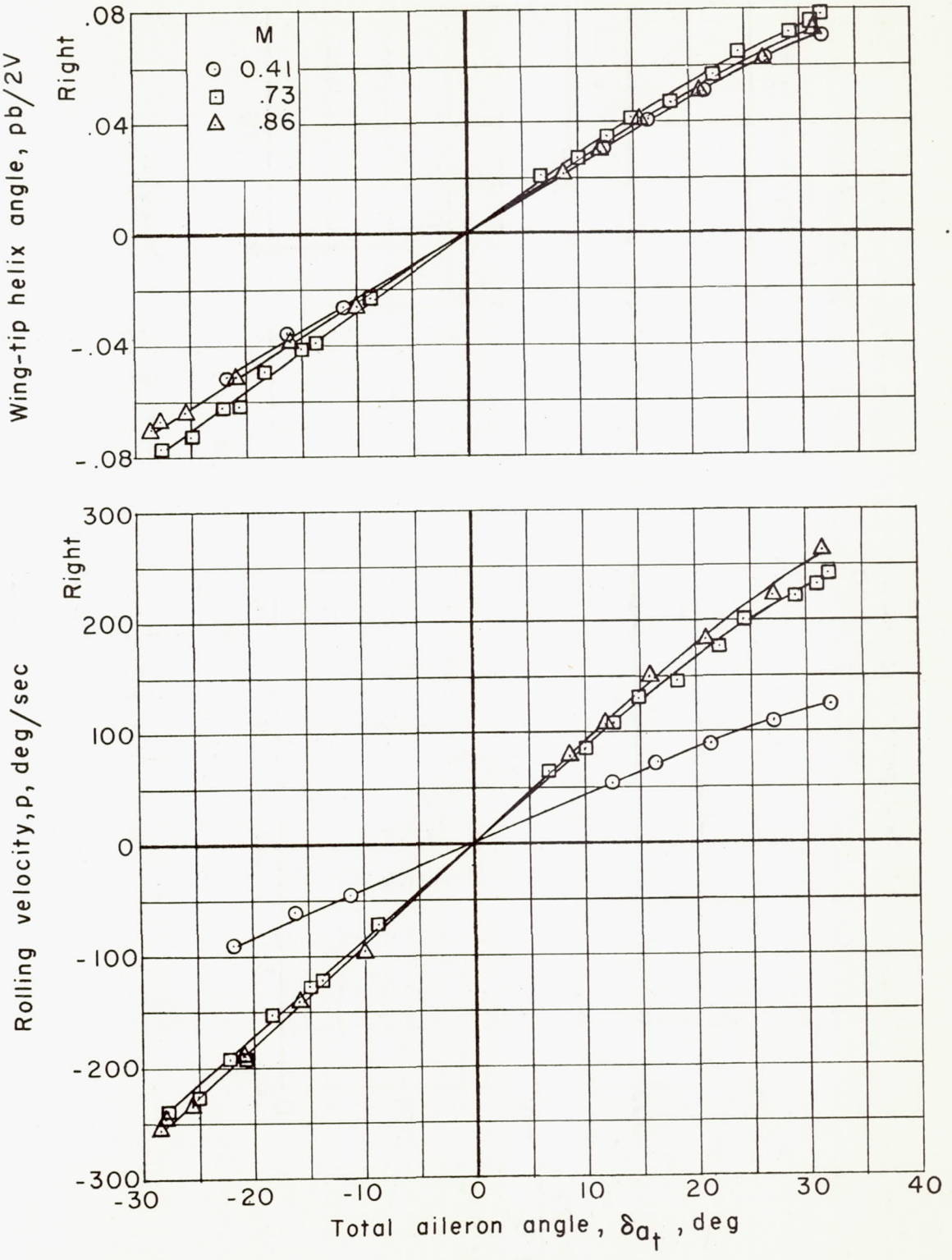


Figure 22.- Lateral control characteristics at 30,000 feet.

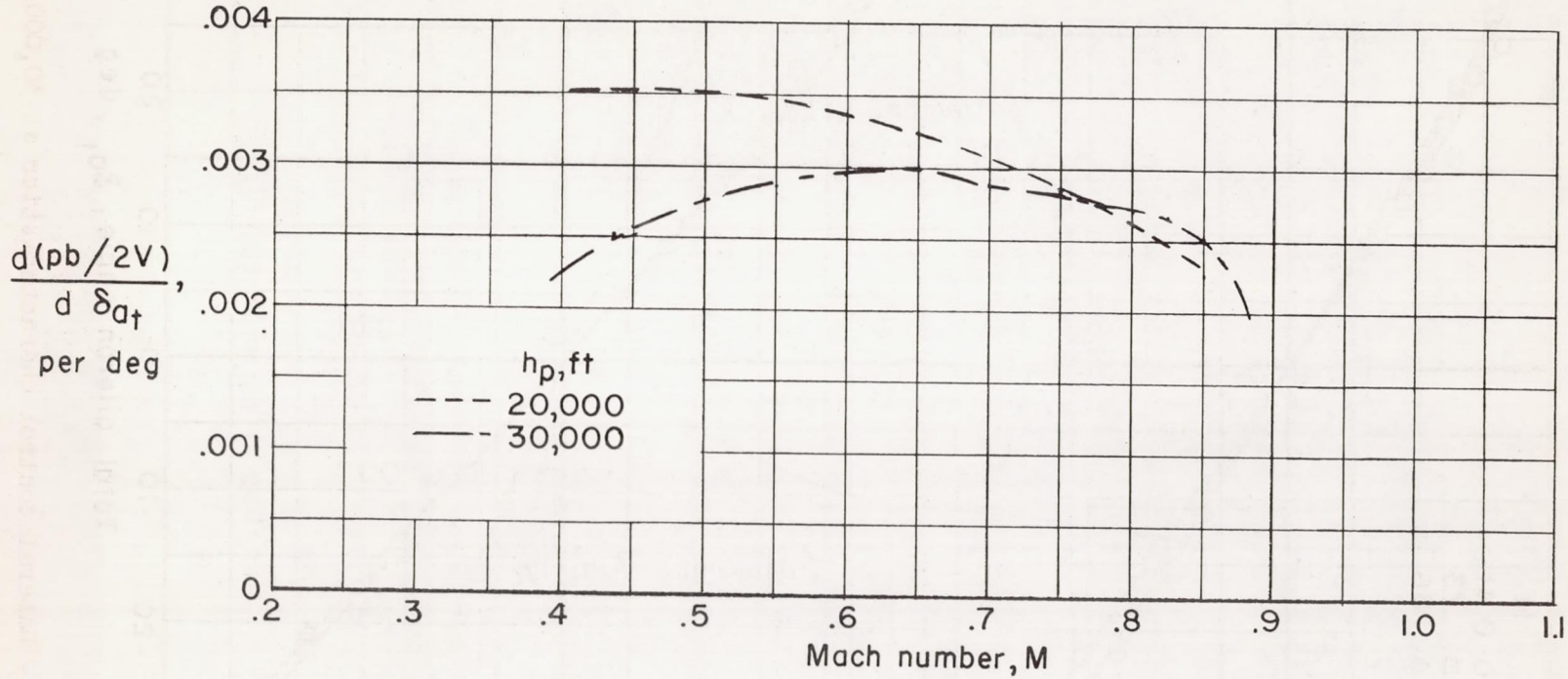


Figure 23.- Variation with Mach number of the wing-tip helix angle developed for a unit total aileron deflection.

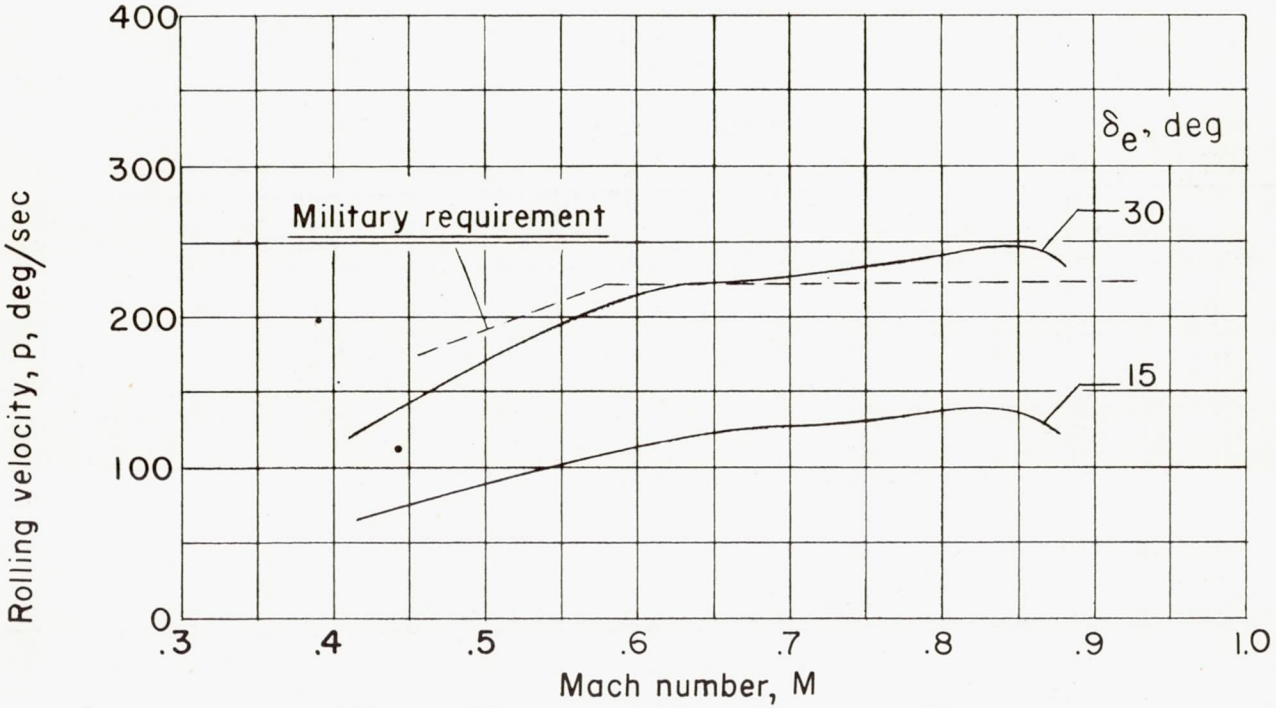


Figure 24.- Variation of rolling velocity with Mach number; h_p = 30,000 feet.

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